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US Army Corps of Engineers  
Water Resources Support Center  
Institute for Water Resources

## INTEGRATION OPPORTUNITIES FOR COMPUTER MODELS, METHODS, AND GIS USED IN CORPS PLANNING STUDIES

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13. ABSTRACT (Maximum 200 words) The report surveys models, methods and geographic information systems (GIS) used in water resources planning by the Corps of Engineers and suggests opportunities for integrating these tools to improve planning and decision-making. Information on models, methods and GIS was gathered via completed planning studies, a literature survey and interviews with planners and researchers at Corps laboratories, other technical centers and District offices. An inventory of planning tools discovered during the information-gathering process is included in the report. The report identifies several issues that will affect the integration of planning tools, including the difficulty of matching the needs of the user with the tool, data issues, hardware/software choices and organizational concerns. The report offers four strategies for approaching integration: 1) Development of interfaces for existing models, methods and GIS; 2) Incorporation of spatial functions into models; 3) Incorporation of modeling functions into GIS; 4) Development of Spatial Decision Support Systems (SDSS). Each strategy can be effective although the SDSS approach has considerable merit in addressing Corps planning problems. The report concludes with a description of general activities that should be undertaken by the Corps to facilitate the integration of planning tools for water resources decision-making.			
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## **EXECUTIVE SUMMARY**

The U.S. Army Corps of Engineers (Corps) is a diverse organization with a variety of missions. Planning activities include flood control, navigation, shoreline protection, dredge and fill permitting, emergency operations, and environmental restoration. The Corps has at its disposal an equally diverse array of computer models, methods, and GIS to assist in evaluating technical issues, developing alternatives, evaluating alternatives, selecting plans of action, and implementing those plans. As demands on Corps planning and decision making are increasing, the capabilities of the Corps' tools must be improved.

The objectives of this report are to:

- Outline the Corps water resources planning process and its participants.
- Survey models, methods, and GIS used in water resources planning by the Corps.
- Identify opportunities for integrating models, methods, and GIS to improve the effectiveness of Corps decision making and planning.

To address these objectives, initial efforts were directed towards information gathering. These efforts included review of 20 recently completed Corps planning studies; site visits to selected Corps division offices, district offices, and research facilities; and interviews with persons inside and outside of the Corps with expertise and/or experience in using models and GIS. Although a literature survey was also completed, the most up-to-date information was obtained through interviews.

Table ES-1 lists the recent planning studies reviewed for this project. They are all planning studies available to IWR from the past three years. Although the Corps has many missions, flood control and navigation are the two water resources activities that dominate the studies. As shown in the table and in figure ES-1, the studies cover a wide geographic range.

Figure ES-1 also shows the locations of site visits conducted for this project. Many, though not all, of the new developments in modeling and GIS are taking place at these locations. They are the following:

- Hydrologic Engineering Center.
- Construction Engineering Research Laboratory.
- Waterways Experiment Station.
- Cold Regions Research and Engineering Laboratory.
- Fort Worth District.
- Vicksburg District.
- Lower Mississippi Valley Division.

Review of the planning studies, along with site visits and interviews, contributed to a partial inventory of common tools applied in Corps planning and decision making. The inventory includes nine hydrology and hydraulics models, nine economic models, three water quality models, five shoreline erosion models, and five GIS/data systems. These are listed in Table ES-2. The exact number of models is not important, but they illustrate that the Corps must serve a variety of needs.

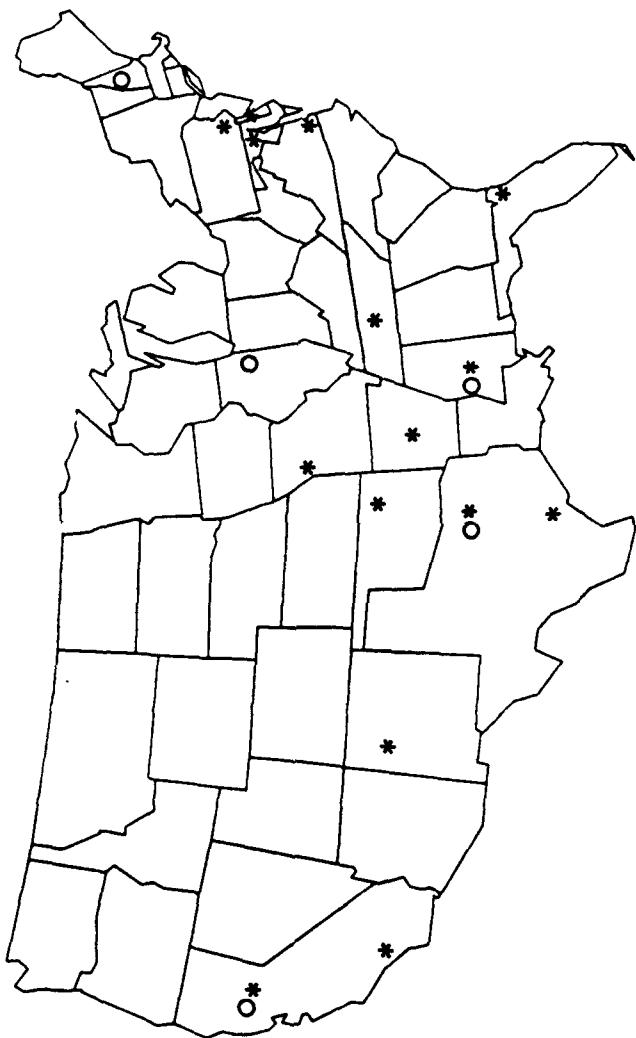
Since the models and GIS are now generally independent from one another and the Corps planning needs are very diverse, a number of issues arise which must be addressed in order to effectively integrate models and GIS to support the Corps activities. Issues identified in the report are:

**Table ES-1.**  
**Planning Studies Reviewed.**

<i>Topic</i>	<i>Primary Mission</i>	<i>Performing Unit(s)</i>	<i>Date Completed</i>
American River Watershed	Flood Control	Sacramento District	12/91
Upper Steele Bayou	Flood Control	Vicksburg District	12/91
Arkansas River Basin	Flood Control	Tulsa & Arkansas Districts	5/91
Shoal Creek, Austin, Texas	Flood Control	Fort Worth District	11/91
Rio Grande and Tributaries	Flood Control	Albuquerque District	12/90
Osage River Basin	Flood Control	Kansas City District	3/90
Eastern North Carolina Above Cape Lookout	Flood Control	Wilmington District	4/91
Cameron County, Texas	Flood Control	Galveston District	10/90
Los Angeles County Drainage Area	Flood Control	Los Angeles District	1/92
Upper Zocate Creek	Flood Control	Fort Worth District	4/92
Canaveral Harbor, Florida	Navigation	Jacksonville District	8/90
Morehead City, North Carolina	Navigation	Wilmington District	6/90
Miami Harbor, Florida	Navigation	Jacksonville District	3/90
Lower Cumberland & Tennessee Rivers	Navigation	Nashville District	11/91
Delaware River	Navigation	Philadelphia District	2/92
Beach Erosion Control	Shoreline Erosion	Wilmington District	12/90
Gulf Intercoastal Waterway	Shoreline Erosion	Galveston District	2/92
Chesapeake Bay Shoreline	Shoreline Erosion	Baltimore District	10/90
Denison Dam - Lake Texoma	Other	Tulsa District	9/90
Trinity River Prototype	Other	Fort Worth District	9/91

**KEY:** ○ = **site visit**  
\* = **planning study**

*Note: Multiple studies and site visits are represented only once*



**Figure ES-1.**  
**Locations of Reviewed Planning Studies and Site Visits.**

- *Hardware/Software* - Models and GIS can and do reside in different environments. For example, of those districts who use GIS, 25 percent use ARC/INFO, 25 percent use Intergraph, 25 percent use GRASS, and 25 percent use other GIS tools. Whatever GIS environment is used, compatibility between GIS and models must be attained in order to ensure that data can be readily transferred between the GIS and models.
- *Data and Data Acquisition* - An explosion of data has been made possible by new technologies such as remote sensing and image processing. This abundance of information raises issues of data precision, standards, and storage. Other data management issues influence choice and application of models and GIS.
- *Corps Authorization and Organization* - The development and application of analysis tools is generally limited to Corps missions. In activities where the Corps is not the lead institution, development of integrated decision-making tools is hampered by authorized authority. Also, the Corps has an active development program at the Corps labs and Districts. These entities must be managed to be productively competitive and not duplicative.

These issues provide the background for identifying and evaluating potential integration opportunities. In addition, four integration strategies are identified to guide the Corps in developing integration priorities. The four strategies are summarized in Table ES-3. Each reflects a legitimate approach to achieving various objectives. The first three strategies address needs of analysts and the decisions they must make in applying and integrating models and GIS. The fourth strategy, spatial decision support, shifts the focus to directly supporting decision makers in unstructured multiple objective decision contexts. Such an approach requires rethinking the model/GIS development process.

A variety of integration opportunities exists which can increase the effectiveness of Corps decision making, particularly as applied to planning. Depending on the target users, these may be oriented toward the analyst or decision makers in the form of spatial decision support systems (SDSS). Some of the possible areas for application include:

Table ES-3.  
Summary of Model/GIS Integration Strategies.

Strategy	Target User	Comments	Corps Examples (1)
I. Development of interfaces for existing models, methods, and GIS.	Analyst	<ul style="list-style-type: none"> <li>Maximum use of existing tools.</li> <li>Immediate benefits.</li> </ul>	<ul style="list-style-type: none"> <li>f-tools developed by the Fort Worth District.</li> <li>HEC-SAM developed by HEC.</li> </ul>
II. Incorporation of spatial (GIS) functions into models.	Analyst	<ul style="list-style-type: none"> <li>Expands visualization and data management in models.</li> <li>Increases utility of modeling tool.</li> <li>Generally requires more development time than strategy I.</li> </ul>	<ul style="list-style-type: none"> <li>NexGen modeling systems being developed by the HEC.</li> </ul>
III. Incorporation of modeling functions into GIS.	Analyst	<ul style="list-style-type: none"> <li>Expands analytical capability of GIS.</li> <li>Increases utility of GIS tool.</li> <li>Generally requires more development time than strategy I.</li> </ul>	<ul style="list-style-type: none"> <li>Incorporation of hydrologic modeling into the Intergraph GIS by WES (hydraulics laboratory).</li> </ul>
IV. Development of Spatial Decision Support Systems (SDSS)	Decision maker	<ul style="list-style-type: none"> <li>Oriented toward decision makers rather than analysts.</li> <li>More radical change in thinking requires longer development time and more training than other strategies.</li> <li>Useful for public communication and information.</li> </ul>	<ul style="list-style-type: none"> <li>TERRACAMMS(2) developed by WES (geotechnical laboratory).</li> <li>Dredging scheduling DSS being developed at IWR.</li> </ul>

(1) Details may be found in the text. (2) Military application.

- Flood Control
- Navigation Assessments
  - Lock and Dam Operational System
  - Navigation Optimization
  - Dredging and Dredged Material Disposal Assessment
- Dredge and Fill Permit Management
- Water Supply System Management
  - Reservoir Operations
  - Conservation/Demand Management
- Natural Resource Management
  - Wetlands Assessment
  - Ecological Habitat Assessment
  - Noise Assessment
  - Groundwater Assessment
- Emergency Operations
- Shoreline Protection Evaluation
- Environmental Restoration

It is clear from the planning study reviews, site visits, and interviews that continued development of models and GIS will take place and that some of the development effort is focussed on integration. It is also clear that a long-term framework must be established to take advantage of evolving GIS and DSS technologies in developing integrated systems that will address future Corps decision-making challenges. In many cases, SDSS is an ideal strategy for understanding and addressing Corps planning efforts. General activities that will enhance pursuit of SDSS and other integration strategies include:

1. Improving communication within the Corps so that both needs and innovations are more widely known;

2. Encouraging the centralized definition of standards and protocols for the interfacing of models, GIS, and data bases, but not the centralized development of SDSS tools;
3. Identifying the most promising candidates for integration from the vast pool of existing models based on relevant characteristics such as the representation of spatial, temporal, and statistical phenomena;
4. Encouraging training in DSS and SDSS technologies and philosophy;
5. Sensitizing Corps software developers to evolving planning needs, especially in less structured decision-making environments ideal for DSS and SDSS;
6. Facilitating discussion of integration priorities in terms of both decision needs (wetlands, flood control, etc.) and technology (user interfaces, object-oriented programming, data protocols, etc.); and
7. Identifying and evaluating SDSS applications outside of the Corps to determine how the issues outlined in this report were addressed, what new issues arose, and how successful the tools have been for decision making.

These conclusions and suggestions, based on studying the Corps planning process, will assist the Corps in exploiting new approaches to developing decision-making tools.

## **I. INTRODUCTION**

The objective of this report is to summarize a survey of models, methods, and GIS used in water resources planning and engineering by the US Army Corps of Engineers (Corps) and to identify ways in which existing and future models, methods, and Geographical Information Systems (GIS) can be integrated to improve Corps planning. The report discusses of the integration of models, methods, and GIS by illustrating how they are currently applied, identifying integration issues, and outlining alternative strategies for integration.

An important Corps mission is research, planning, and management of the nation's water resources. Integration of models, methods, and GIS is not the only means of enhancing Corps capabilities in fulfilling its mission. However, rapid advances in computing technologies combined with an extensive inventory of models suggests that integration will improve Corps capabilities.

The intent of the report is not to specifically review Corps capabilities and types of GIS and models. Because the Corps already has in-agency experts in developing GIS and models, it requires instead a strategy to integrate these tools into a workable system oriented to users in the planning process.

Models, methods, and GIS are chosen based on the problems and issues to be addressed, the type of study being conducted, available information, study complexity, costs, and other factors. A GIS, or any other tool, is not the end product of a study. However, a GIS can be used effectively to obtain selected input data and output displays for analysis, and can be a repository of information for future use with models or other methods.

The report focuses on the following questions:

- What decisions are made at each stage of the planning process, and who makes them?
- What are the models, methods, and GIS used in the planning process, and how are they used?
- What can be done to improve effectiveness of these tools in the planning process; in particular, what strategies for integrating models, methods, and GIS would be effective?

The following sections examine models and methods used by the Corps in completing water resources missions. The PLANNING STUDIES section describes the contents of Corps flood control, navigation, and shoreline protection studies, which are primary Corps missions and the topics of most reconnaissance and feasibility studies. (Appendix A contains additional information related to the planning studies.) Other study topics addressed by Corps planners are also included. (Site visits and interviews, discussed in Appendix B, are the sources of this important supplementary information.) The INVENTORY OF APPLICATIONS section discusses the particular models and methods described in Corps planning reports. (More details on the models and methods are within Appendix C.) The section on INTEGRATION ISSUES summarizes problems which practitioners inside and outside the Corps have identified as current or future constraints for integration of models and GIS. The section on INTEGRATION OPPORTUNITIES describes areas in which planning can be improved through integration. The CONCLUSION section provides a synopsis of the report findings and suggests future direction for the Corps in integrating models and GIS.

## **II. PLANNING STUDY REVIEWS**

Authorized and justified by a Congressional resolution or an act of Congress, the purpose of a planning study is to investigate a water resources issue, proposal, or problem that relates to the overall Corps mission. The planning studies (or reports) may include reconnaissance, feasibility, or environmental assessment functions, and the investigation may lead to action on one or more water resources missions (typically flood control, navigation, and/or shoreline protection). Corps planners and engineers at the district level are usually responsible for producing planning studies. Personnel from Corps research facilities provide additional technical support on an as-needed basis.

### **THE PLANNING PROCESS**

In preparing a planning study, the Corps first completes a reconnaissance study to identify and prioritize specific water resource problems to be addressed in feasibility studies. Then draft, interim, and final feasibility reports evaluate the economic and environmental consequences of the alternatives proposed to address project objectives. Environmental consequences are typically expressed in either environmental assessments or more comprehensive environmental impact statements (EIS). The Corps balances ecological and public interests through the EIS process as required by the National Environmental Policy Act (NEPA). Planners usually establish issues, propose alternatives, rank alternatives based on economic criteria, and offer a preferred alternative plan. A major criterion determining study success or failure is economic feasibility, and therefore, most studies incorporate benefit to cost analyses for proposed mitigation measures.

The Corps distributes draft feasibility reports to government agencies and other interested parties for review and comment. The District Engineers must approve final feasibility and EIS/EA reports. Congress, through its budget authority, must approve implementation of report plans. Figure 1 depicts the general stages in the Corps planning process.

Each stage in the planning process is defined and constrained by:

- the objectives of the study;
- the required level of justification to accept one of the alternatives;
- the available time and budget for each planning stage; and
- the tasks that must be accomplished to meet the objectives.

These constraints often determine whether it is practical to use models and/or GIS at a given stage of the planning process. At times, appropriate tools are available from a technical standpoint, but cannot be effectively applied given institutional and/or resource constraints.

In order to better understand the planning process and the role of models and GIS in that process, a review of several recent planning studies was conducted. All reconnaissance and feasibility studies prepared by Corps districts during the last three years which were accessible to the Institute for Water Resources (IWR) were reviewed. Each was assessed to determine the following:

- the study objectives;
- the approach used to achieve the objectives;
- the success in achieving the objectives;
- the modeling and GIS tools applied in the study; and
- the contribution of the models and GIS in achieving stated objectives.

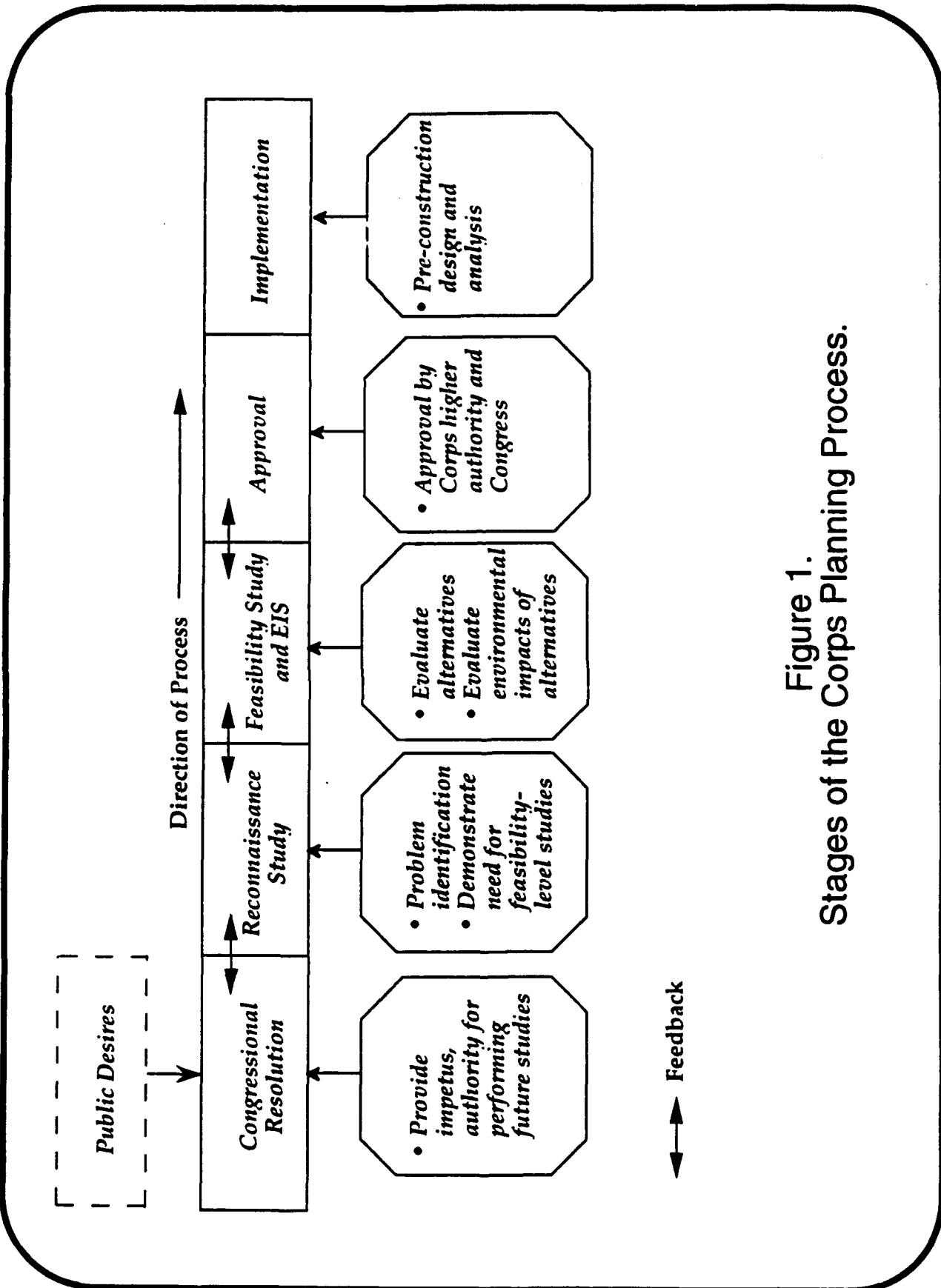


Figure 1.  
Stages of the Corps Planning Process.

Table 1 summarizes key elements of the study reviews. (More detailed information is found in Appendix A.) The studies include a range of report types including reconnaissance, feasibility, and other for the flood control, navigation, shoreline protection, and other missions. The table shows the type of analyses pursued in addressing study objectives including engineering, economic, and environmental analyses. It also indicates whether or not models and/or GIS were applied in the study.

Not all of the studies achieved their objectives of finding cost-effective alternatives in response to perceived inadequacies and/or desired improvements. In these cases, the success of a study and the role of models and GIS in achieving study objectives must be assessed in terms of avoiding implementation of alternatives less desirable than the no action alternative. In studies where one or more proposed alternatives are determined to be cost effective, success of a study, and the role of models and GIS, is more easily assessed.

#### SELECTED INTEGRATION EXPERIENCES

Review of the planning studies revealed examples of significant efforts made by District offices to integrate existing modeling and GIS tools to better achieve various objectives. Because identification of future opportunities is informed by understanding existing achievements, the following three projects deserve particular note. Information on other models and GIS tools applied in recent Corps planning studies is presented in Appendix C.

The Fort Worth District has developed useful tools, integrating GIS technology with hydraulic and economic models, in its prototype study for the Upper Trinity River Study. Their floodplain analysis tool kit, *f-tools* which was developed by Mother Earth<sup>1</sup> systems, integrates GRASS, HEC-2, and an economic flood damage model. The analysis tools use previously developed HEC-2 output as input. First, the *f-tools* kit creates cross-section maps with water surface elevations calculated by HEC-2. GRASS can display these vector maps.

---

<sup>1</sup>Mention of product names is not an endorsement by the U.S. Army Corps of Engineers and is included only for the information of the reader.

Table 1. List of Corps Reports Reviewed.

R E P O R T C A T E G O R Y	FLOOD CONTROL		EIS      X      X	
	A N A L Y T I C A L T O O L S			
	E N V I R O N M E N T A L			
	E C O N O M I C			
	E N G I N E E R I N G			
	T Y P E O F A N A L Y S E S			
	O T H E R			
	F E A S I B I L I T Y			
	R E C O N N A I S S A N C E			
	R E P O R T C A T E G O R Y			
American River Watershed	X			
Upper Steele Bayou	X	X	EIS      X      X	
Arkansas River Basin	X	X	X      X	
Shoal Creek, Austin, Texas	X	X	X      X	
Rio Grande and Tributaries	X	X	EA      X	
Osage River Basin	X	X	X	
Eastern North Carolina Above Cape Lookout	X	X		
Cameron County, Texas	X	X	X      X	
Los Angeles County Drainage Area	X	X	EIS      X      X	
Upper Zocate Creek	X	X	EA      X      X	

Table 1. List of Corps Reports Reviewed (continued).

REPORT CATEGORY	REPORT NUMBER	ENVIRONMENTAL ANALYSIS		ECONOMIC ANALYSIS		TYPE OF ANALYSIS		FEASIBILITY		REPORTS		MODELS		OTHER	
		Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool
<b>NAVIGATION</b>															
Canaveral Harbor, Florida															
Morehead City, North Carolina															
Miami Harbor, Florida															
Lower Cumberland & Tennessee Rivers															
Delaware River															
<b>SHORELINE EROSION</b>															
Beach Erosion Control															
Gulf Intercoastal Waterway															
Chesapeake Bay Shoreline															
<b>OTHER STUDIES</b>															
Denison Dam - Lake Texoma															
Upper Trinity River Basin															

An interactive program then manipulates the maps to compute different floodplain delineations for different storm events. The kit allows examination of flood depths at various points within the floodplain, permitting flood damage analysis for a particular storm.

The *f-tools* also allow for an economic damage analysis using information from a GRASS data coverage and HEC-2 flood elevations. Building inventory GRASS coverage includes, for each structure, an identifier, structure value, contents value, and a flood depth versus percent damage curve. Water surface elevations calculated by HEC-2 are also used by the GIS to generate economic reports estimating total flood damage. The reports include flood damage estimates for each building in the study area, for each specified flood event, and for individual buildings during a given year.

The *f-tools* can obtain specific hydraulic information when a mouse is used on the GRASS-generated maps. The kit determines floodwater statistics such as areal extent of flooding, average flood depth, and volume of floodwater. The tools provide these statistics for a selected reach between any two adjacent cross sections. One *f-tools* feature is the ability to graphically manipulate cross sections on a floodplain map for re-analysis. The analyst can add, erase, or move cross sections to a new location, while generating the appropriate data for input to HEC-2.

A computerized technique called Spatial Analysis Methodology (SAM), developed by the Corps' Hydrologic Engineering Center, was applied by the Philadelphia District in the Delaware River Comprehensive Navigation Study. In this case, SAM was used to determine the relative attractiveness of placement sites for dredged material. SAM represents an integration of two main components--a data base of spatial data representing physiographic characteristics and a series of computer programs designed to perform utility and analysis functions. The methodology involves collecting and storing necessary mapped data in the computer, defining the criteria for screening sites, instructing the computer to search the data base for areas having the desired combination of characteristics, and displaying the results in graphical or tabular form for further analysis.

In the Upper Steele Bayou Reformulation Study, a GIS was modified to aid in determining project impacts, specifically the effects of project alternatives on waterfowl carrying capacity. Although the methodology did not involve the integration of models and GIS, the GIS was tailored to incorporate specific analysis methods which identified acres of available foraging habitats under baseline (no project) conditions and in the future when the various project alternatives would be completed.

Several examples of GIS and model integration exist outside of the Corps. One is a storm water management analysis of the Broadhead Creek watershed in Pennsylvania (*DeBarry, 1990*). The analysts used GIS as a tool to develop data bases of physical features which include land use, soil group, and subbasin boundaries. These GIS parameters were input to computer rainfall/runoff simulation models such as HEC-1 or SWMM. Digitally recorded data of subwatershed boundaries, soil group, and land use were gathered to produce spatial and attribute files. The analysts developed an intermediate program to compute input parameters (percent impervious cover and runoff curve number) for the hydrologic model, eliminating the need for manual input of data. The GIS generated existing and future land use maps for analysis. Movement from GIS (input) to model to GIS (output) required intermediate action by the user which was facilitated by the integration of model and GIS. Other instances of integration of GIS with water resources models include applications to hydraulic/hydrologic analyses, economic damage assessment, air quality, and water quality studies (*Thompson, 1991*).

Other integration efforts have been pursued outside of the water resources field. For example, market research investigations have combined GIS and numerical modeling to determine potential commercial opportunities (*Goodchild, 1991*).

### **III. INVENTORY OF APPLICATIONS**

This section discusses models, methods, and GIS applied in the planning reports. The section is divided according to four general Corps missions: flood control, navigation, shoreline protection, and other applications. More detailed information on the models and GIS is available in Appendix C.

#### **FLOOD CONTROL**

Most of the planning studies addressed flood control issues. Operationally, flood control analyses are divided into separate sequences that lend themselves to computerization, beginning with the prediction of the design storm or flow (hydrology). The studies next determine how the flow affects water levels under existing conditions and when proposed flood control measures are implemented (hydraulics). These results allow calculation of damages and costs of solutions (economics). Finally, the studies explore additional social, health, and environmental concerns, when applicable (water quality).

The variety of models and geographic information systems listed in Table 2 reflects the importance of flood control in the Corps mission. The flood control software systems are typically mature, having gone through several versions and applications, and are available on a variety of computer platforms. In some cases, the systems may be applied for purposes beyond flood control. This is especially true for the geographic information systems that are often useful in addressing multiple Corps missions.

Table 2. Selected Analytical Tools for Flood Control.

FLOOD CONTROL		Hydrology	Hydraulics	Groundwater	Economics	Environmental*
S	P					X
H	E					
S	T					
A	R	C	I	-	N	F
C	E	R	R	S	S	
G	R	A	S	S		X
H	E	C	-	S		
Q	U	A	L	-	W	2
E	I	F	S			
C	A	C	F	D	A	S
S	I	D				
E	A	D				
S	U	P	E	R		
G	I	M				
F	L	O	W	2	D	
H	E	C	-	2		
S	W	F	H	Y	D	
N	U	D	A	L	L	A
S	W	M	M			
W	R	C	-	7	B	
H	E	C	-	1		

## Restoration, wetlands, water quality, habitat.

## Models

*Hydrology* - Hydrology models quantify the runoff or flow that results from some precipitation event. In a flood control context, flow measurement allows determination of water surface elevations in watershed channels and streams. Determining the quantity of flow corresponding to a storm event is usually the first step in computing flood control evaluations. Computer models aid this process by simulating the discrete elements of the runoff process. Input to the runoff models may be actual or synthesized data. Two classes of hydrologic models exist: stochastic and deterministic. Stochastic models statistically manipulate measured data, such as rainfall or streamflow, to calculate a design flow. The deterministic models use empirical and theoretical concepts to simulate the creation and movement of runoff.

*Hydraulics* - Hydraulic models determine the effects of flow on a channel or stream. For open channel flows, the models calculate the water surface elevations. For groundwater, the models simulate flow movement from point to point or from one boundary to another. In all cases, conservation of energy and mass is used to simulate the effect of flow on a system. Most open channel models are one-dimensional models, although one study used a two-dimensional model to evaluate a more complex floodplain. Only one groundwater model appeared in the planning studies. The Corps also uses physical hydraulic models to simulate complex hydraulic systems. However, computer models are rapidly replacing physical models.

*Economics/Flood Damage Assessment* - Typically, flood control studies included economic models to determine costs associated with structural and agricultural damages resulting from storm events. The studies used cost estimates to perform benefit to cost analyses on alternative project plans, and only those project plans that contribute to the NED as economically feasible were considered. Many planning studies contain desktop or spreadsheet models to calculate the economic costs and alternatives. The spreadsheet packages easily organize and calibrate data.

*Water Quality* - Water quality issues are usually ancillary to flood control studies. The Corps studies mention, but do not detail, several water quality constituent transport and fate models, including the Corps models HEC-5Q and CL-QUAL-W2 as well as the EPA-sponsored models HSPF and SWMM. The Vicksburg District reports that it has used GIS to aid in calibrating and delineating reaches for the SWMM and HSPF models for Upper Yazoo projects. The GIS is also used to compare model outputs of turbidity and suspended solids loadings to stream cover.

#### Geographic Information Systems/Databases

*Geographic Information Systems* - Geographic information systems are still a relatively new technology. The difficulty in transferring data from one GIS to another is one indication of the emergent nature of GIS and model integration. Another is consistency in data acquisition and application. Several studies note the challenge of merging spatial information from different sources with different scales. Most of the flood control planning studies did not use a geographic information system. Often, a CAD or data base was used to organize input and output data, and these lack the spatial synthesis characteristic of geographic information systems.

*Databases and Other Systems* - Databases provide models and geographic information systems with the organized information required to perform analyses. These data bases contain topology, water resources, environmental, demographic, and geographic information.

#### NAVIGATION

Five of the Corps planning reports were navigation studies, which addressed the enlargement of harbor channels to allow increased shipping traffic. Each study included economic analyses for alternative project plans to determine which ones were economically justified (based on NED criteria). Table 3 lists the models used in the navigation reports. Most

of the models were economic in nature, but methodologies varied from report to report. Accompanying environmental impact statements used salinity models to determine project effects on salinity distribution in the waterways.

Table 3. Selected Analytical Tools for Navigation.

	S H O A L I N G	D R E D G E	D 2 M 2	D R I	T C M	T S I M	S A L I N T Y	S A M
<b>NAVIGATION</b>								
Economics	X	X	X	X	X			
Environmental						X	X	X
Other		X				X		X

#### Models

*Economic* - Economic benefits of alternative plans were typically determined by using market projections based on increased channel navigability. Calculation of benefits is a methodology which can be computerized in a spreadsheet format.

*Water Quality* - A pair of salinity models which estimate saltwater intrusion was the extent of water quality modeling efforts in the navigation reports.

### Geographic Information Systems/Spatial Analysis Systems

*Spatial Analysis Systems* - The planning studies included an application of a spatial analysis system which performed data management and analysis functions to determine suitable dredge spoil regions. Similar to a GIS, SAM allows synthesis of spatially arranged data. The results permit visual analysis of the sites affected by the dredge spoil.

### SHORELINE PROTECTION

Three Corps planning studies addressed shoreline protection for threatened coastal communities. Each of the studies analyzed alternative plans based on NED criteria. The emphasis in the recommended projects was on redirection of hurricane and storm damages and beach erosion as well as enhancing beach strands for recreational use. Table 4 lists the analytical methods and applications (all models) used in the studies.

Table 4. Selected Analytical Tools for Shoreline Erosion.

	A C E S	T O P S A I L	C O A S T	S B E A C H	
<b>SHORELINE EROSION</b>					
Hydrology		X			
Hydraulics	X	X			
Shoreline Change			X	X	
Economics			X		

## Models

*Hydraulics/Hydrology* - Shoreline or coastal hydraulics models typically analyze for wind speed, wave height, tides, and variation in sea level. For the shoreline reports reviewed, the Corps used only one hydraulic model to determine wave height. However, one additional report used equations for coastal hydraulics. These equations would lend themselves to a simple spreadsheet model.

*Shoreline Change* - The Gulf Intercoastal Waterway study included several shoreline change models, which can determine the rate and extent of change by comparing past and present site information. This information can be used to develop statistical and empirical relationships in order to forecast future shoreline movement and positions. The SBEACH model simulates beach nourishment scenarios to assist in determining annual nourishment requirements.

*Economics* - Each shoreline protection plan was screened to determine economic feasibility of a proposed alternative. The NED plan, or the plan with the highest benefit to cost ratio, was chosen if an economically justifiable project existed. Storm damage computer programs and real estate appraisal data in a spreadsheet format allowed calculation of economic benefits and costs to compare alternative plans. Other models estimate average annual flood damages, by an approximation of the structural value of affected structures, of storms and hurricanes. These models estimate annual maintenance costs of the surveyed projects based on a percentage of damage or the initial cost of the protection structure. The economic analyses consider benefits derived from project alternatives including navigation benefits (e.g., prevention of delays), storage cost benefits, added maintenance dredging benefits, and incidental benefits from bridges, roads, structures, lands, and recreation.

## OTHER APPLICATIONS

One planning study evaluated hydropower, water supply, navigation, flood control, and recreational uses of a lake created by the Corps. The potential for producing additional hydroelectric power provided the impetus for the planning study. The POWERSYM model was used to simulate the introduction of additional power into the nearby electrical grid. The alternative proved to be neither necessary nor economically feasible, effectively ending the venture. Analytical tools were not used to address the water supply, flood control, navigation, and recreational aspects of the project.

In the Upper Steele Bayou Project, FORFLO, a bottom-land hardwoods succession model, simulated the tree growth in the project area. The model allows prediction of the extent and fate of wildlife habitat.

Many Corps planning studies are performed in cooperation with other Federal agencies or with state/local entities. At times, these study partners introduce their own models and GIS into the planning process. For example, the Fish and Wildlife Service (FWS) applied a GIS with HEC-1 routings to provide inputs to their energy model for waterfowl in the Upper Steele Bayou and Upper Yazoo projects. These tools assisted in evaluating environmental impacts.

#### **IV. INTEGRATION ISSUES**

Several issues shape the identification and evaluation of opportunities for integrating models, methods, and GIS in Corps water resources planning activities:

- Who are the target users of resulting advancements?
- What types of models and GIS systems are available and how do they currently interface with one another?
- What are the hardware and software technologies needed to support integration and are they available?
- Do the data necessary to support integration exist and who is responsible for collecting and maintaining the data?
- How well suited is the current Corps organization for developing and maintaining new tools and what limitations are imposed on the Corps by law?

In order to identify reasonable integration opportunities, it is instructive to acknowledge how these questions have shaped the development of technologies and the ways those technologies are currently applied by the Corps. These questions also determine, in part, what can be accomplished in the foreseeable future.

## TARGET USERS

There are a variety of participants in a water resources study including planners and/or engineers, the study manager, the District Engineer, and the policy makers. Each is responsible for a different part of the planning process and requires suitable tools to carry out that responsibility:

- *Planners/Engineers* - These professionals are the core of a study team and are responsible for data collection and detailed technical analysis of project alternatives.
- *Study Managers* - These professionals supervise the planners and engineers and are responsible for the overall completion of the study including evaluation of appropriate alternatives and addressing the objectives of the study.
- *District Engineers* - These professionals must target available resources to the most appropriate studies and provide approval of planning studies before they are submitted to the Division and/or Corps headquarters.
- *Policy Makers* - These professionals must evaluate the overall conduct of Corps activities and balance competing interests within and outside the Corps.

Most of the methodologies applied in Corps planning studies are targeted for use by the planner and/or engineer to evaluate the merits of various project alternatives. They are intended to facilitate the use of models and GIS by project engineers, scientists, and planners. That is, they make the analyst's job easier and/or more effective, but may require considerable technical expertise to implement. The results of the analyses are then summarized in tabular or graphic form and are included in a report provided to Corps decision makers. For example, the USGS enhanced their 2-D and 3-D groundwater models, such as MODFLOW, to include graphical and spatial input and output processors. Specifically, an ARC/INFO interface for MODFLOW called MODFLOW-ARC makes the model easier for engineers and scientists to use but does not make

it more accessible to those without a modeling background. Its purpose is to eliminate some of the tedium in preparing input data sets and presenting results.

Other types of tools not presently prevalent may target alternative groups of users such as Corps decision-makers, project sponsors, cost-sharing partners, and the general public. Integration efforts directed towards participation in this arena must respond to different technical and operational objectives. For example, real time (i.e., rapid) response of analytical tools are more important to decision-makers wishing to explore options during a workshop than to most analysts. Similarly, the models must be straightforward so that participants in a working or decision-making forum, who may or may not have a technical background, not only understand but trust the model.

Another way to identify appropriate tools for a targeted group of users is to determine whether planning or management decisions are being made on either a strategic or tactical level. Broadly defined, strategic decisions tend to be oriented toward larger policy issues while tactical decisions tend to be more specific and analytically oriented. Strategic analysis may provide the framework in which to develop alternatives. Tactical analysis methods would include simulation and review of alternatives. Appropriate tools for each type of decision-making may require different characteristics.

## MODEL/GIS TYPES

The ability to integrate models and GIS is influenced by the characteristics of the models and GIS as well as the objectives and data requirements of users. GIS products are generally available in either a raster or vector format, although some products are beginning to obscure this distinction by including both capabilities. The selection of an appropriate tool for a given task depends on which of these formats better represents the relevant data and on the importance of mass storage and processing time. Current research exploring expansion of GIS types by investigation of 3-D GIS, object-oriented GIS, and time variable (animated) GIS is discussed by Burroughs (1989).

Model types also vary greatly in their basic characteristics. Chan, Maidment, and Mays (1988) have developed a taxonomy of models related to the ways they characterize space, time, and randomness. Spatial representation is either lumped or distributed, time variation is either time variant or steady state, and randomness is deterministic versus stochastic. While many models cannot be so clearly classified, a deterministic, distributed, and steady state model may be a stronger candidate for integration with GIS in the near term because these types are most compatible with the characteristics of GIS. In the longer term, more extensive modification of other models, or development of new models, may yield productive integration opportunities.

The interfaces between models and GIS and among models present additional issues. Most models and GIS products are designed to interact with a user--not with each other. Common data storage and transfer protocols are not widely used. "Open" language standards, such as ANSI provide guidance that programmers use to create products which can be used with diverse hardware platforms. Other protocols may be provided, as "closed" or proprietary. These open and closed approaches compete for dominance in the user community. At best, the open approach results in widely disseminated and understood operating systems such as UNIX, but UNIX may also be an example of the worst in an operating system. The large number of UNIX versions causes problems in maintaining standards and protocols (Yager, *et al.*, 1992). Interagency efforts currently underway seek to develop and enhance these protocols (Rubin, *et al.*, 1992). Some protocols (such as .DXF files) become "de facto" standards because of the popularity of CADD systems in the user community.

## HARDWARE/SOFTWARE

Integration opportunities are shaped by the compatibility of the hardware and software necessary to apply GIS and models as well as the availability of this hardware and software to the target user(s). Such issues can be explicitly considered in the design of new tools, but may pose significant barriers to integrating existing tools. A variety of hardware types, such as PC, Macintosh, and Intergraph can cause barriers for sharing programming and data resources. At the same time, limiting the platform to a particular vendor limits the range of potential users. With respect to GIS usage in the Corps, it is estimated that, of those Districts who use GIS, 25 percent use ARC/INFO, 25 percent use INTERGRAPH, 25 percent use GRASS, and 25 percent use other GIS platforms (*Gauthier, 1992*). Each GIS platform requires different data formats. GIS and model developers must risk that their application will be designed for a hardware/software platform that survives the test of time. In other words, if a GIS is chosen which is not widely used or distributed, there is the potential that it will not be adequately supported in the future.

The desired capabilities of a particular tool (e.g., graphics, computational power, and data storage) are affected by the selection of hardware/software. If inappropriately selected, hardware/software may limit the utility of the tool. At times, the cost and expertise necessary to acquire and operate hardware and software limits distribution and use of an otherwise useful tool.

Keys to evaluating integration opportunities between models and GIS include the modularity and portability of software onto a variety of hardware platforms. Operating systems (e.g., DOS, VMS, OS/2, and UNIX) come with alternative capabilities and supporters. However, technology is continually improving, and newer approaches to programming and application development might be available in the foreseeable future. Object-oriented programming, a new way of describing models, exemplifies the evolution in technology. Standardization of common user access (CUA) and graphical user interfaces (GUI) also assists in providing a consistent programming approach.

## DATA AND DATA ACQUISITION

*"Garbage in results in garbage out."* Expanding availability of spatially-referenced data and the growing ability of GIS and models to use these data have not altered this timeless observation. Integration of models and GIS offers the additional challenge to provide sufficient data on a scale compatible with the models and GIS. The availability, resolution, accuracy, and maintenance of data are critical to successful model/GIS integration. When similar data are collected over time, special problems of data collection technologies, resolution, and accuracy can result. Converting and integrating spatial data available at different scales or resolutions can be a significant challenge. Acquisition, quality assessment, and storage of data may equal or exceed the level of effort applied in the so-called "analysis" portion of a study.

Data acquisition technologies, such as remote sensing and image processing, have resulted in an explosion of available data describing the earth's surface. Image processing involves using satellite or other imagery to make quantitative assessments based on computerized images of different land features. The images distinguish land features using spectral (electromagnetic) data and image processing tools assign different digital numbers to unique features. This technology permits environmental analyses through the computer classification of satellite data. The satellite data can reveal distinctions in soil, rock and vegetation, as well as heavy metal and other contaminants around landfills and containment facilities. Hydrogeologic modelers use image processing to determine land use factors and percent impervious cover. However, some data sources are still under development, and only partial coverage of the United States is currently available. Others exist nationally, but may not be on a scale appropriate for site-specific studies.

## CORPS AUTHORIZATION AND ORGANIZATION

Each of the planning, design, and implementation issues discussed above is superimposed on the way in which the Corps conducts its business. As a part of the Federal Government, much of its activity is spelled out in legislation. Furthermore, the Corps is discouraged from competing with other Federal partners, state and local government, and the private sector. The Corps activities reviewed in the planning studies and discussed in site visits are dominated by missions in flood control and navigation. Other activities are conducted, but the models and GIS applications used by the Corps are generally both responsive to and limited by Corps missions. Organizational limits must also be accepted in identifying realistic integration opportunities. The Corps' concern about operating within its authority is exemplified in a study by Johnson and DiBuono (1992) in which a data base and report documenting the many authorized purposes of Corps' reservoirs was prepared.

Within the Corps, an organizational structure also defines how things are accomplished. Although difficult to change, organizational constraints can be removed by the Corps if sufficient motivation is provided. The Corps is a multi-faceted organization with both civilian and military functions. Its activities range from military base management to battlefield support to water resources planning and management. In the course of pursuing various activities, the Corps must perform a variety of tasks ranging from technical analysis to planning, to communication, to persuasion.

Many of the civilian activities, such as planning studies, are performed at the District level. Tools applied are supplied by a variety of sources, including one of the Corps research arms, such as HEC, other government agencies, universities, and commercial vendors. Some tools are developed in-house. Responsibility for model and GIS development and support is, therefore, widely dispersed. The Corps also represents a significant user and experience base in GIS and CAD with various CAD and GIS centers located throughout the Corps. One could reasonably expect that integration opportunities would have to be identified with these realities in mind.

Within the Districts, the use and promotion of analytical tools and GIS varies depending on a combination of available expertise and circumstances. For example, the responsibility for the use and development of GIS may fall in a variety of places including operations, planning, surveying, and engineering. Usually, those divisions in a district that use GIS the most become, by default, the "leaders" in their districts.

## V. INTEGRATION OPPORTUNITIES

The preceding chapters report on the broad array of models, methods, and GIS applied in Corps water resources planning studies, as well as applications outside of the Corps. This chapter focuses on how these models, methods, and GIS may be integrated, or otherwise improved, to expand their utility to the Corps.

### INTEGRATION STRATEGIES

Integration, in the context of this report, is the direct linkage of models and GIS so that manual manipulation of inputs and outputs is unnecessary. Models, methods, and GIS can be integrated in a variety of ways depending upon the target user, technical objectives, decision-making objectives, model availability, budget, etc. However, most integration efforts can be generally characterized in one of four ways:

- Development of interfaces for existing models, methods, and GIS;
- Incorporation of spatial (GIS) functions into models;
- Incorporation of modeling functions into GIS; and
- Development of spatial decision support systems (SDSS).

These four integration strategies, summarized in Figure 2, do **not** describe a mutually exclusive set of integration options nor do they represent a continuum on which one strategy is superior to another for all circumstances. Instead, they represent alternative perspectives for approaching integration. The intended user, the level of sophistication of existing models, methods, and GIS, the type of questions requiring answers, and the resources available for implementation will greatly influence which strategy is most appropriate.

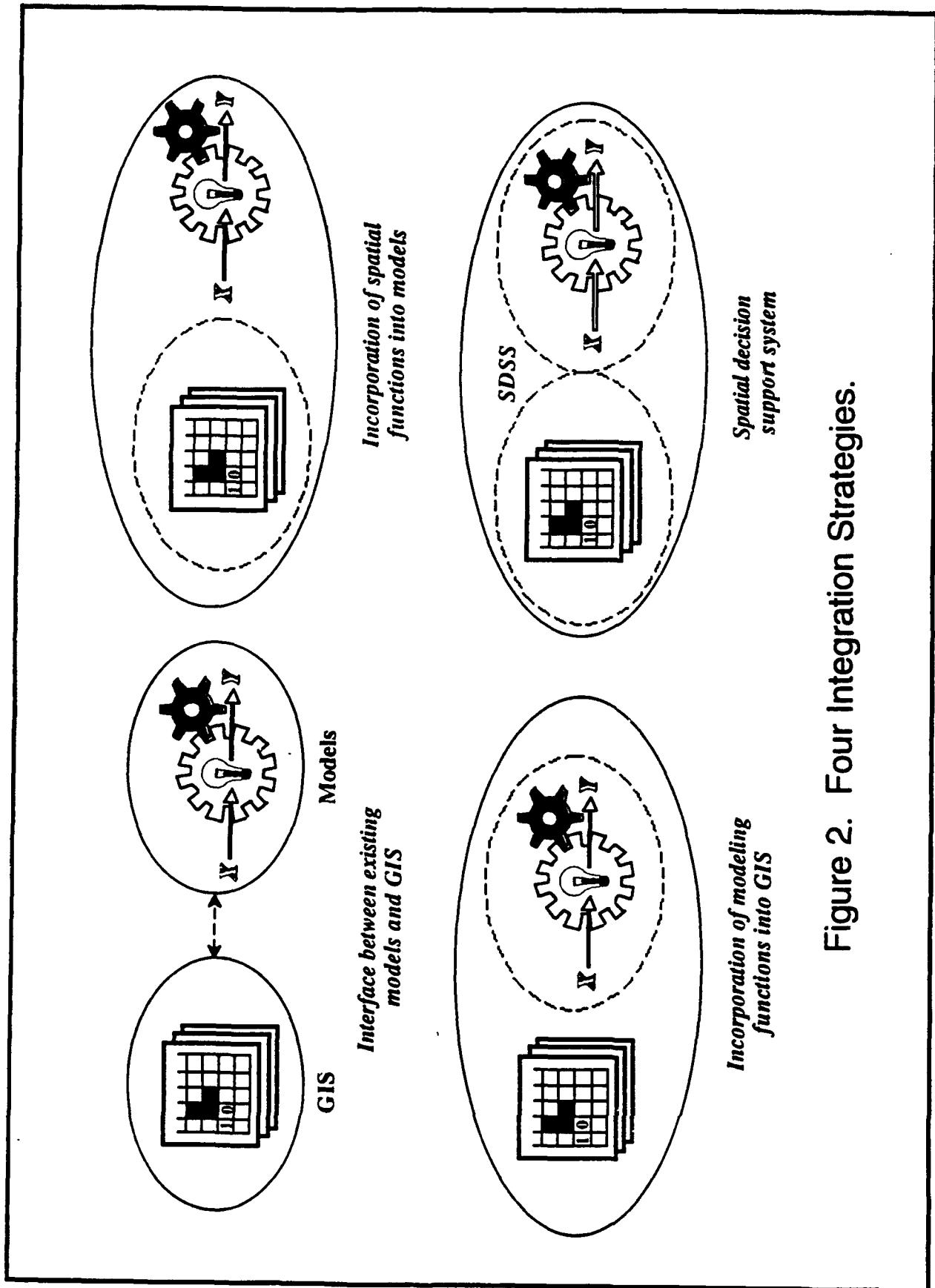


Figure 2. Four Integration Strategies.

### Interfaces for Existing Tools

Development of interfaces for existing models and GIS is an evolutionary approach to linking existing analytical tools. These links typically involve development of tools for pre- and post-processing model input and output and/or translating data to accommodate different software data format requirements. Models are accepted as they are and the linkages serve to automate manual activities. Computer programs written to translate GIS data for automated creation of a HEC-2 input data set and to translate HEC-2 output data for display by a GIS are examples of this integration strategy. The use of "*f-tools*" in the Fort Worth prototype study and the HEC-SAM software are examples of this approach. The latter includes a variety of computer programs with specific linkage functions. For example, the program HYDPAR generates hydrologic data from spatial grid data for use in HEC-1. Figure 3 describes a generic flood control analysis system using the integration strategy of developing interfaces for existing models and GIS.

The conceptual strengths of interfaces depends upon the maturity and stability of the existing models and GIS. The interface provides the translation and control mechanisms without necessitating that current models and GIS be recoded. A well designed and implemented system may appear seamless to the user. However, the use of specific models and GIS locks the system into a specific configuration. Major changes or upgrades to modeling and GIS components may require modification of the interface.

### GIS Functions in Models

The incorporation of spatial data functions into models is an alternative strategy which establishes the model as the primary component and endeavors to improve spatial representation, analysis, and presentation of the data. That is, data analysis and spatial

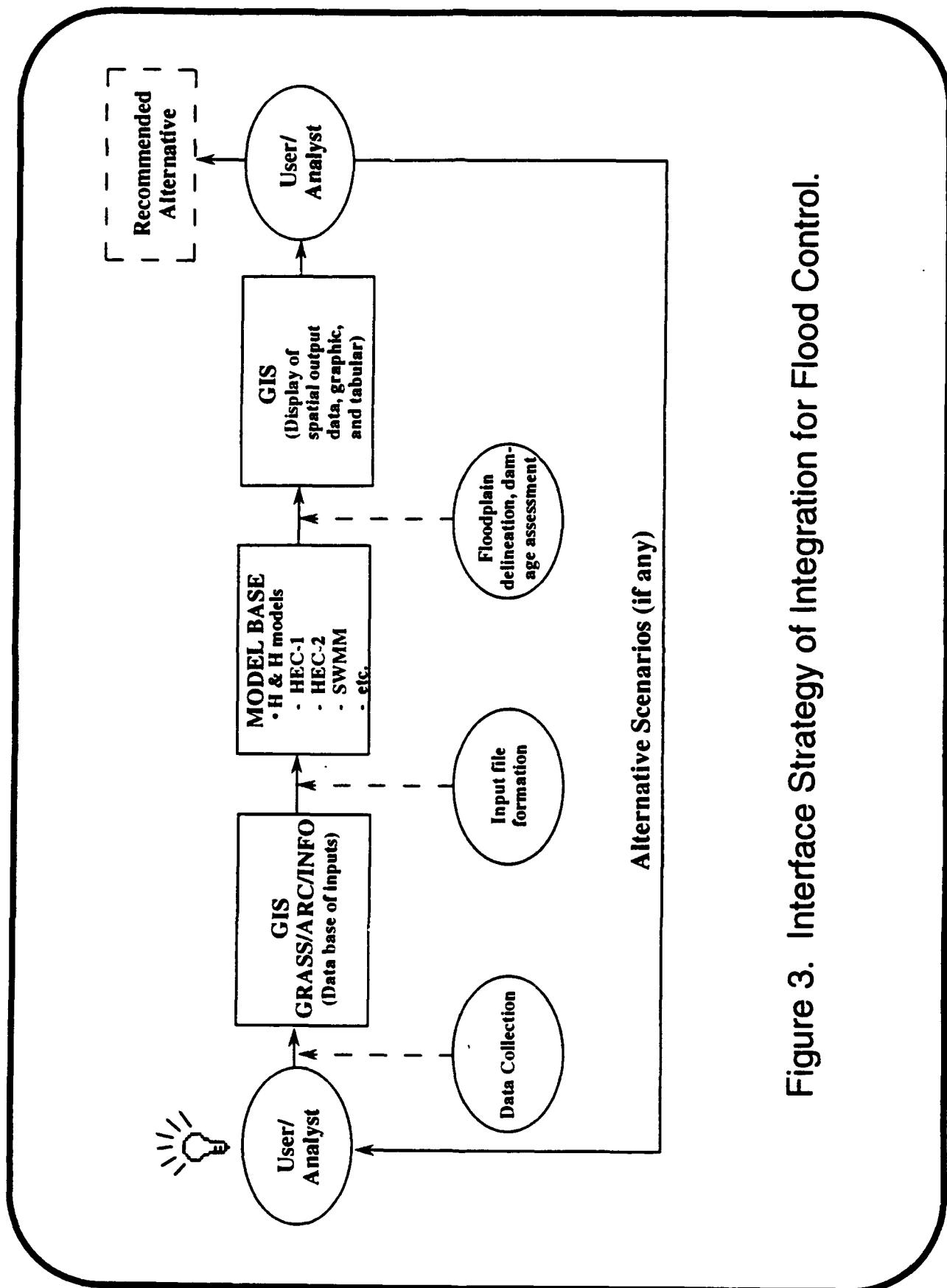


Figure 3. Interface Strategy of Integration for Flood Control.

display features are solely directed toward servicing a central modeling capability. The **NexGen** software packages being developed at the HEC are examples of this approach toward integration. Such an approach generally serves to increase the sophistication of models representing spatial phenomena by improving the characterization and interpretation of model input and output data.

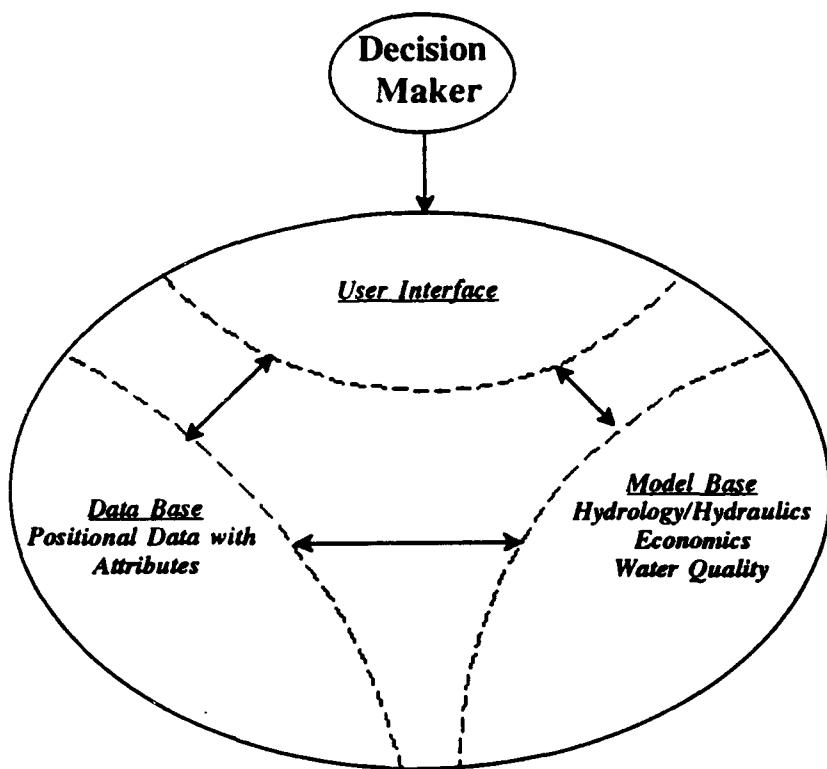
### Modeling Functions in GIS

The addition of modeling capabilities into GIS programs represents a third view of integration. This approach is the inverse of the prior approach. Here the spatial data, analysis, and display capabilities are of central importance and modeling is added as an enhancement. Modeling, as used in this context, is more than the basic manipulation of data by combining various data coverages within the GIS. Such capabilities are often called application modules or tool kits by GIS developers. For application modules with a dominant spatial orientation, integration of models can add significant analytical capabilities to a GIS.

### Spatial Decision Support Systems

The final integration strategy is that of a **Spatial Decision Support System**, as described by Walsh (1992). A Spatial Decision Support System (SDSS) merges GIS and Decision Support System (DSS) technologies. GIS offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data. DSS are interactive programs, often with a graphical user interface, that may incorporate models and expert systems to assist decision makers. Figure 4 represents the SDSS and its components.

One example of an SDSS in the Corps is **TERRACAMMS** (Condensed Army Mobility Model) which is used for battlefield decision making. It includes a variety of models simulating weapons performance and includes a geographical data base which supports



Derived from: Walsh (1992)

Figure 4. Representation of a Spatial Decision Support System for Water Resources.

multiple models. Its graphical user interface provides the user with access to the models and data and presents the resulting information for real-time decision making. The model system was developed and continues to be enhanced at the Geotechnical Laboratory at WES. Examples of decision support systems within the Corps include a schedule DSS developed at the U.S. Army Strategic Defense Command in Huntsville, Alabama, and a budgeting DSS developed at the Institute for Water Resources at Fort Belvoir, Virginia.

SDSS is a strategy that requires significant user input to develop the specific decision-making environment and address problems. Developers, e.g., modelers and/or GIS experts, must be trained in DSS development and the regulatory process, as well as being sensitive to the needs expressed by potential users. The needs for technical users and decision makers are much different. Understanding that SDSS is more appropriate for decision making than resolution of specific technical questions is important for development of a useful SDSS. The development of prototypes is often useful in encouraging developers and users to exchange essential information.

## APPLICATION OPPORTUNITIES

Review of the planning studies and discussions with Corps scientists, engineers, and planners reveal potential opportunities for applying models, methods, and GIS in an increasingly integrated and effective manner. Many opportunities are already being pursued at Corps laboratories and other research facilities as well as in the Districts where analytical tools are usually applied. However, such efforts are duplicated at times because information is not centrally coordinated and disseminated Corps-wide. Conversely, overly burdensome central coordination can stifle innovation and discourage development of expertise at many locations within the Corps. Therefore, management approaches toward the integration of models, methods, and GIS will influence the selection and pursuit of opportunities. However, management recommendations are beyond the scope of this report.

Because the Corps is a diverse organization with a variety of missions, numerous modeling and GIS tools are used. The following list of functional areas demonstrates the broad planning interests of the Corps:

- Flood Control
- Navigation Assessments
  - Lock and Dam Operational System
  - Navigation Optimization
  - Dredging and Dredged Material Disposal Assessment
- Dredge and Fill Permit Management
- Water Supply System Management
  - Reservoir Operations
  - Conservation/Demand Management
- Natural Resource Management
  - Wetlands Assessment
  - Ecological Habitat Assessment
  - Noise Assessment
  - Groundwater Assessment
- Emergency Operations
- Shoreline Protection Evaluation
- Environmental Restoration

Some of these areas represent traditional missions, within which integration efforts are underway. Others are newer activities where integration remains conceptual in nature. The Corps must assess its needs for developing integrated tools and prioritize those that will have the greatest benefits. This requires sensitivity to the integration issues identified and discussed in the previous chapter. In the remainder of this chapter, topics are selected from the above list and the need, promise, and reality of developing integrated tools is discussed.

## Flood Control

The Corps has invested significant resources into the development and maintenance of models and GIS tools to assist in fulfilling its flood control mandate. Although they vary from study to study, typical functional needs in flood control studies include:

- *Hydrology* - Selection and estimation of the magnitude and duration of a storm event and the resulting runoff;
- *Hydraulics* - Calculation of flood levels in channel waterways and floodplains in response to estimated runoff; and
- *Damage estimation* - Estimation of damage to agricultural, residential, commercial, and industrial land uses as a function of flood levels.

Efforts to integrate spatial analysis with modeling tools using a variety of strategies have already been conducted by the Corps to a limited extent. A pioneering effort being conducted in the Fort Worth District exemplifies the strategy of applying interfaces through the development of *f-tools*. Several years ago, the same strategy was used by HEC in developing HEC-SAM. Currently, HEC has committed significant resources to the development of NexGen which can be characterized as an integration of spatial data analysis and presentation into a modeling framework. Work recently accomplished as a result of the Oahe Dam Safety Exercise, September 1992, at Omaha District and CRREL with contributions from the other Corps laboratories, is a similar attempt.

Other examples applicable to flood control are found outside the Corps. Use of the SDSS approach is increasing, but applications are frequently referred to by other names. Lynn Johnson (1990) describes an application where a computer-aided planning (CAP) system was developed to facilitate decision-making and public involvement in multi-objective reservoir operations. The

CAP tool includes a model for physical simulation of the reservoir, a model for valuation of decision-maker criteria and preferences, a spreadsheet for graphical presentation of results, and a graphics library for animation of alternatives. This application did not include a GIS, nor was the application significantly spatially referenced. Sheer, *et al.*, (1989) have developed a similar tool for making water resource allocation decisions called Computer Aided Negotiations.

These accomplishments and continuing efforts within and outside the Corps raise the question of whether or not additional opportunities for integration exist. Certainly, flood control is a major responsibility, and while few new dams will be built in the coming years, flood control is a broader activity than dam sizing and construction. It includes consideration of levees and non-structural management approaches to flood forecasting, warning, and release rates. Demand has also increased for the Corps to manage existing dams to meet multiple purposes: recreation, water supply, hydropower, in-stream flow, and others. Such a shift in the types of questions asked will put new demands on Corps engineers, scientists, and planners, and by extension, on the tools they use. Decision makers may become more involved in formulating model runs as the need to balance competing objectives grows.

For these reasons, flood control analysis may benefit from further integration efforts using the SDSS strategy. In an SDSS, the spatial data base (GIS) and the model base would be coupled components of an overall support system architecture which allows for quick and easy screening of alternatives through a user interface. The model base would consist of analytical tools applied by the Corps in flood control studies. They would be adapted to respond to the user through the user interface and to interact automatically with the data base to retrieve and store data. The data base organized through a GIS would support the models in terms of input requirements and output display. The GIS provides the data base which represents the land environment (soils, land use, etc.) from which the inputs for the hydrologic models can be built. Also, GIS can provide the display capabilities to represent output results in graphical and tabular formats. While the user/analyst can be a technical user, the SDSS concept is oriented toward decision makers.

Both Johnson and Sheer (et al.) developed their tools in a specific decision-making context for a specific site. The success of each effort was achieved, in part, by the simplicity and site-specific nature of the tools and by user input on decision-making needs. This experience suggests that the greatest integration opportunities in flood control may not be to design and develop a grand SDSS system for a certain class of decisions, but rather, to provide a compatible collection of tools that can be integrated at the time they are needed for specific problems that must be addressed at a specific site.

To target development of integrable tools rather than an integrated tool is to recognize the following:

- The Corps is already integrating several tools, such as *f-tools* and NexGen.
- Grandiose systems are often too general to be useful in any specific circumstance.
- The Corps possesses significant expertise in modeling and GIS that could be enhanced by better information exchange.
- The development of interface and data base standards Corps-wide can assist in the development of integrable tools.
- For decision-making purposes, the greatest modeling need for flood control is in the development of optimization tools that assist in weighing competing objectives and presenting near-optimal solutions.

Better information exchange, data standards, and interface standards, combined with the existing Corps' wealth of modeling and GIS tools and expertise offers tremendous potential for improving flood control planning with SDSS. Better information and data exchange standards will facilitate a free market exchange between buyers who are decision-makers and the sellers who are model/GIS developers. The benefit of competition within the Corps is that the tools that

can be integrated to assist decision-makers will survive, while those that cannot will be left behind.

### Navigation

For nearly 100 years, the Corps has possessed regulatory jurisdiction to maintain the navigability of public waterways, including harbors, rivers, or canals (*River and Harbor Act, 1899*). Over the past thirty years, their regulatory authority has been broadened to reflect environmental concerns. Frequently, Congress requests navigation studies and projects of the Corps. These studies focus on the consequences of various alternatives for facilitating shipping traffic through a waterway. Typical economic and engineering factors in navigation planning studies include:

- *Economic and market responses.* Changes in types, costs, and availability of a commodity over time. Commodities include raw materials, manufactured goods, and bulk items traded on the national and international marketplace.
- *Shipping methods.* The nature, quantity, and limitations of available transportation resources.
- *Channelization and dredging efforts.* The physical nature of the waterway that allows movement from point to point.
- *Environmental concerns.* Ecological consequences of the first three factors.

Economic and market projections frequently provide the impetus for a study because changes in the types and costs of commodities influence the continued economic viability of a port. The types of available shipping methods are tied to particular commodities and may reflect changes in shipping technologies or intermodal transfer requirements. Physical characteristics

of the waterways dictate the sizes and numbers of ships that may be accommodated. For example, increases in imported petroleum demand require increased numbers of larger ships. Larger ships require deeper and wider channels for safe navigation. Frequently, alternatives to meet increased demands on the navigation system involve dredging. Dredging, and the disposal of the resulting spoil material, constitute a primary ecological issue.

Integrated decision-making tools must address the above factors. However, the Corps mission does not include regulation of commodity markets and/or shipping technologies. Design conditions are generally provided to the Corps based on new navigation needs. Therefore, a decision support system that would assist in dredging and environmental analyses would be appropriate. Such a system may provide the user with the following capabilities and resources:

- *Channel Location.* The ability to select alternative channel layouts and locations enables response to physical changes and optimization of routes. For example, the channel may be moved to an area with a more stable bottom composition (thus reducing the frequency of dredging).
- *Waterway Hydrography.* The National Oceanographic and Atmospheric Administration (NOAA) has digitized underwater hydrographic information associated with US waterways. The information consists of waterbody, shoreline, and channel characteristics. Waterbody information contains water depth referenced to a datum (typically mean sea level). The channel profiles are provided by Corps district offices, sometimes in digitized format (Enabnit, 1992).
- *Bottom Composition.* The bottom material affects both removal options and channel design. NOAA maintains digitized data that provide some of this information (Enabnit, 1992).

- *Dynamic Analysis.* Modeling the accretion and erosion of the channel over time allows estimates of the frequency of dredging. A channel located at an area where the bottom has a better resistance to tractive shear force will be more stable than channels with a lower resistance to shear.
- *Spoils Disposal.* The Corps has used HEC-SAM to assist in determining a spoils disposal location. A GIS is an ideal tool for performing overlay (McHargian) analyses of sites. Functional requirements for disposal sites could be internal to the tool and/or externally produced during the planning process by decision makers.
- *Spoils Site Capacity.* It is also necessary to forecast the capacity and expected lifetime of a disposal site. The Corps has produced an optimization strategy for determining spoil site capacities and lifespans (*Ford, 1986*).
- *Environmental Concerns.* The changes or effects on the environment as a result of the dredging operations must be assessed. For example, spoil material may contain concentrations of undesirable materials. The location of the spoils area may affect the habitats of aquatic and terrestrial wildlife.

Several models, such as D2M2 and HEC-SAM, are already available to perform some of these tasks. The GIS offers the abilities to spatially portray the channel bottom. Topographic "cut-and-fill" algorithms can estimate the volume of dredging required to meet a design depth. A new model component could provide information on the stability of a channel section. A new model could also simulate the filling of a channel for forecasting dredging scheduling. As channel geometry changes environmental and hydrodynamic transport and fate models of the physical system may be needed to evaluate environmental effects of altered circulation patterns in the waterway. Changes in salinity are another potential environmental consequence.

Another example of a current Corps effort is a DSS to support dredge managers, under development at IWR. This cooperative effort between IWR, WES, and the New Orleans District is intended to assist a dredge manager in deciding when and where to mobilize dredges. As conceived, it will include three modeling components--sedimentation, shipping benefits, and dredging costs/productivity--all managed by an interactive shell operated by the user. The work is expected to be completed in two years if necessary funding levels are realized (*Skaggs, 1993*).

In a practical integration context, both the interface development and SDSS strategies offer a framework on which to create an entire dredging assessment system. The interface development strategy would use the existing models and spatial data and create linkages between them. For example, a tool to retrieve the NOAA and Corps channel hydrography data bases to generate D2M2 input data sets is feasible. The advantage of this strategy is that the spatial data (GIS) and the models would not require modification. The interfaces would perform the data management efforts. The limitation of this strategy is that the resulting system would be constrained by the existing modeling capabilities and hierarchy. That is, the relationship between the modeling and data would be rigidly specified by the interfaces.

The design of a SDSS architecture offers greater flexibility in dredging assessment. An object-oriented approach may prove ideal to implementing this strategy. Modularity of the tasks allows greater flexibility of the system. For example, a dredging assessment system might initially present the user with a graphical representation of a navigation site. By using a pointing device to select an option (represented as an icon), the analyst could instruct the system to perform a specific task. For example, graphically overlaying a proposed channel shape over the existing section of the waterbody could illustrate the volume of dredged material required. The task results would be presented as both graphic and numerical output. The advantage of such an integration strategy is that it would reduce the need for a strictly linear approach to decision making. While a variety of options are available to the user, only those of interest would need to be selected.

## Water Supply

Corps oversight of water supply systems results from a site-specific role mandated by Congress (i.e., water supply uses designated in the authorization of a reservoir project), management of water supplies on military installations, and at times, fulfillment of its regulatory role in 404 permitting. Other water supply management roles emerge from time to time. Regardless of the reasons for involvement, however, the purpose of technical assessment is generally to determine whether an existing or potential water supply can be better managed for beneficial uses. At times, environmental impact statements may require investigations into conservation and other demand management measures to evaluate the need for new supplies. Typical functions that relate to water supply system management include:

- *Demand Forecasting.* Efforts to manage an existing or future water supply system must address changes that will result in decreased or increased demand. These changes may have natural and man-made causes.
- *Water Quality Assessment.* Water quality assessment tools assist in evaluating the effects of contamination events on the supply. Water quality assessment may include treatment requirements, salinity encroachment, and pollution.
- *Supply Reliability.* Deterministic and stochastic methodologies are available to assess the reliability of a system in delivering water.
- *Transmission and Distribution Network Characteristics.* It is necessary to assess the physical characteristics and capabilities of the transport, storage, and delivery elements that influence the efficiency of the entire network. Tracking and simulating these elements allows better expansion and maintenance decisions.

- *Cost Estimating.* Evaluating the costs of different water supply alternatives facilitates decision making.

The disparate requirements of water supply management combined with the Corps' varied mission suggests that integration of all functions into a single system is unlikely to be beneficial to the Corps. However, integration opportunities for elements of water supply systems may still be achievable. The Corps has been involved in some of these activities.

#### Demand Forecasting

Demand forecasting is an attempt to simulate the relationship between demand and the factors that influence demand, including:

- Economic and demographic development.
- Long-term changes in climate (temperature and precipitation).
- Extreme climate effects (drought).
- Demand management strategies.

Analytical tools such as models and GIS are ideally suited for highlighting trends and forecasting demand in a region, and such tools exist to aid in demand forecasting. The IWR-MAIN model already provides forecasting capabilities. GIS-based census data and other sources provide economic and demographic information. TIGER census information provides numerous accurate data elements. The demand forecast system could offer planners the ability to simulate effects of constraints on demand (i.e., water rates conservation measures, changes in demand allocations). Models capable of evaluating climatological and hydrological information can be used to calculate the baseline values for extreme and long-term climate effects.

An SDSS composed of appropriate models and geographic data could be useful for decision making or communication with the public. For example, during a public hearing, an SDSS could display demands as a function of a service area. The analyses may also permit

planners to identify areas experiencing extremes in demands. This could facilitate targeting of areas needing educational or regulatory information.

### Water Quality Assessment

Water supplies derived from surface waters are vulnerable to contamination from pollutants carried aboard ships or from shoreline sources. The January 2, 1988, Pittsburgh (Monongahela River) oil spill is an example of these vulnerabilities. During the event, a primary concern was the fate and transport of the spill downstream--particularly as it affected the water supply intakes on the river. With no decision support systems in place, it was difficult to determine when the spill would reach an intake and how long it would stay (*Germann, 1988*). The technology does exist to model such spills, but no tool currently exists which would allow for real-time analysis. A tool to address these emergency situations could be developed under the Corps' mission to manage navigable waters. Such a decision support system might include the following:

- *Spatial Information.* These data would locate the sources and locations of industrial discharges and water supply intakes. The U.S. EPA has databases of industrial dischargers throughout the United States which could be used for inputs.
- *Hydrodynamic Modeling.* A hydrodynamic model would calculate the movement of water in a waterway. The model would interface with topographic and bathymetric data to develop linkages and elements that simulate the transport.
- *Contaminant Fate Modeling.* Models to simulate the advection, dispersion, and decay of contaminants would be needed. The models could simulate multi-order decay of materials. For constituents such as salinity, mass is conserved. For pollutants such as oil or pesticides, more complex breakdown and transport mechanisms would have to be accommodated. A graphical interface could be developed which depicts in real time the progression of contaminants in the waterway.

Elements of this approach have been developed in a water supply protection context (*GKY and Associates, 1986a; GKY and Associates, 1986b*). The integration of GIS data would increase the efficiency of the approach by reducing manual data manipulation. Interfaces could adapt spatial information to determine depths, volumes, and flow paths for the hydrodynamic model.

### Transmission and Distribution

Integration of tools to simulate transmission and distribution systems may include data management, hydraulic, statistical, hydrologic, economic, demographic, and environmental modules. The system might be developed for users with a wide diversity of needs and experience. However, the complexity of specific water supply systems (including system-specific infrastructure, legal, political, and social issues) may preclude a generically applicable comprehensive management system. Corps development of such a tool may over-extend interpretation of Corps missions.

### Environmental Regulation and Restoration

Corps responsibilities include efforts to regulate environmental impacts of public and/or private activities. The Corps responsibilities also extend to environmental restoration activities and programs pertaining to hazardous waste, including individual wetlands permit operations, toxic waste site evaluations (*Scuderi, 1992*), and large-scale restorations of entire river basins, such as the Kissimmee River in South Florida (*Glass, 1987*). These activities may exceed the traditional perceptions of Corps missions.

### Groundwater Contamination

The Corps is increasingly applying its engineering expertise in hazardous waste management. One of the greatest technical challenges is understanding subsurface migration of contaminants. There are examples of simulation modules being integrated with existing spatial

platforms (*Rubin, et al., 1992*). Groundwater decision tools could support a subset of opportunities that include tracking waste sites, evaluating toxic releases, and developing remedial designs.

### Wetlands

A focus of Corps regulatory responsibilities is the protection and management of wetlands. This responsibility is derived from its role in permitting dredge and fill operations under Section 404 of the Clean Water Act. However, Corps responsibility and authority are limited by two factors. First, Corps policies and regulatory authority are shared with other Federal, state, and local entities. Second, the Corps permitting authority is difficult to apply to cumulative future effects as opposed to incremental effects. This limitation is, in part, a result of using NEPA as a basis for evaluating impacts. As a result, the Corps permitting program seeks to balance competing "public interest" factors on an incremental basis (*Stakhiv, 1988*).

Wetlands assessment requires more qualitative evaluation of cultural values as opposed to quantitative descriptions of wetland functions. This is based on the distinction between the ecological functions of wetlands, that can be framed in a scientific context, and recreational, cultural, and aesthetic attributes (*Stakhiv, 1988*). Many factors contribute to the functional status of a wetland:

- *Location.* Wetlands exhibit differing ecological and physical characteristics and values based on their location in the watershed. Upland wetlands do not have the same types of benefits as do wetlands located at a shoreline. However, both types provide benefits to the entire watershed.
- *Hydrology.* Hydrology drives the wetlands. The hydrology can be surface or groundwater and affect discharge or recharge functions.
- *Soils.* The hydric soils associated with wetlands are created by hydrologic factors. The hydrologic processes may not be apparent; however, these soils are not formed without some regular flood events.
- *Vegetation.* Plant life will vary based on the location of the wetland within the watershed. Wetland species also perform varying ecological functions depending on their locations in the watershed.

At a scientific level, Corps efforts are targeted towards identifying whether or not mitigation for wetland losses elsewhere provides equivalent physical functions in a watershed. For example, if an existing wetland provides a primary function of sediment trapment, any replacement wetland should provide an equivalent ability if the existing wetland is going to be modified for other purposes. Analytical tools must meet the challenges of functional assessment.

Opportunities for integrating analytical tools to support Corps planning in wetlands assessment can be realized at many different levels. For example, a simple analytical system could employ a GIS to perform McHargian analyses of soil, hydrology, and vegetative characteristics to identify existing wetlands and to locate potential mitigation sites. Corps planners could evaluate these results with respect to pending permit requests for dredge and fill operations to determine if the permit is justified. Walsh (1992) proposes a more comprehensive

decision support system for evaluating permitting decisions affecting wetlands. It includes a sophisticated user interface, a broad model base, and a data base.

Several opportunities for integrating existing and new tools to improve Corps planning are discussed in this chapter. Many others may be conceived with little difficulty in the Corps' water resources mission as well as in other Corps missions. Four strategies for integrating models, methods, and GIS have also been outlined, all of which are being pursued in varying degrees within and/or beyond the Corps. For several of the integration opportunities described, the strategy of developing an SDSS offers significant potential for improving decision making in the face of increasingly demanding planning challenges.

## VI. CONCLUSION

The increasing integration of models, methods, and GIS is inevitable. What remains is to develop an understanding of what needs to be done, the possible pitfalls, and the likely benefits so that resources applied to integration may be used to their fullest potential. At the outset of this report, several questions were posed to focus the investigation.

The first question addressed the need to know what types of decisions are being made at each stage in the planning process and who makes them. The depth and breadth of Corps planning activities are significant and continue to grow. The planning process in water resources involves reconnaissance studies, feasibility studies, design, environmental impact statements and assessments, and other activities. Depending on the purpose of a study and its implications, some technical decisions are made by engineers, planners, and scientists. Other decisions must be made at higher levels in the Corps where multi-objective economic, policy, and/or political choices dominate. These decisions are frequently coordinated with Congressional sponsors, other Federal agencies, and/or state and local partners. Between these levels of decision making are also the study manager, who supervises the engineering and planning activities, and the District Engineer. Each type of decision making demands integrated tools with different attributes.

The second question explored the availability and capabilities of models, methods, and GIS applied in the planning process. An array of tools exists which parallels the depth and breadth of planning activities. In some cases, such as the use of HEC-1 and HEC-2 in flood studies, well tested models--developed and supported by the Corps--are widely applied. In other cases, models developed in-house are created by a Corps unit to meet a specific need. Whether or not other units of the Corps may have similar needs, such models are thinly documented and largely unknown. Many of the planning activities include a significant spatial component which might

be better addressed by integrating and improving the capabilities of models and GIS. Integration benefits may range from simply allowing a computer to perform tedious data management and conversion functions, to harnessing improved visualization capabilities for reviewing data and modeling results, to providing powerful systems with an array of capabilities housed in a common user interface to support decision making.

The third and final question addressed possible strategies to improve the planning process, particularly through integration of models, methods, and GIS. It is clear from the planning study reviews, site visits, and interviews that continued development of models and GIS will take place and that some of the development effort is focused on integration. Figure 5 depicts the range of opportunities possible in a 3-D matrix described by the type of decision maker involved, the mission scope, and the integration strategy. Although a broad range of possibilities exists, appropriate tools must be designed for the type of decision maker and decisions targeted. For example, the figure suggests that development of integrated modeling and GIS capabilities using the SDSS strategy may be an appropriate technology if the target decision maker is a policy maker or District Engineer, but is unlikely to be a good strategy for the engineer or planner. Whether or not it is appropriate also depends on the type of decisions to be supported.

The development of DSS and SDSS requires a longer term vision and commitment than the other integration strategies. The benefit, which generally occurs at the higher levels of decision making, can be achieved by establishing a framework to take advantage of evolving GIS and DSS technologies. Such a framework must include:

- A user-centered orientation toward DSS and SDSS design and implementation;

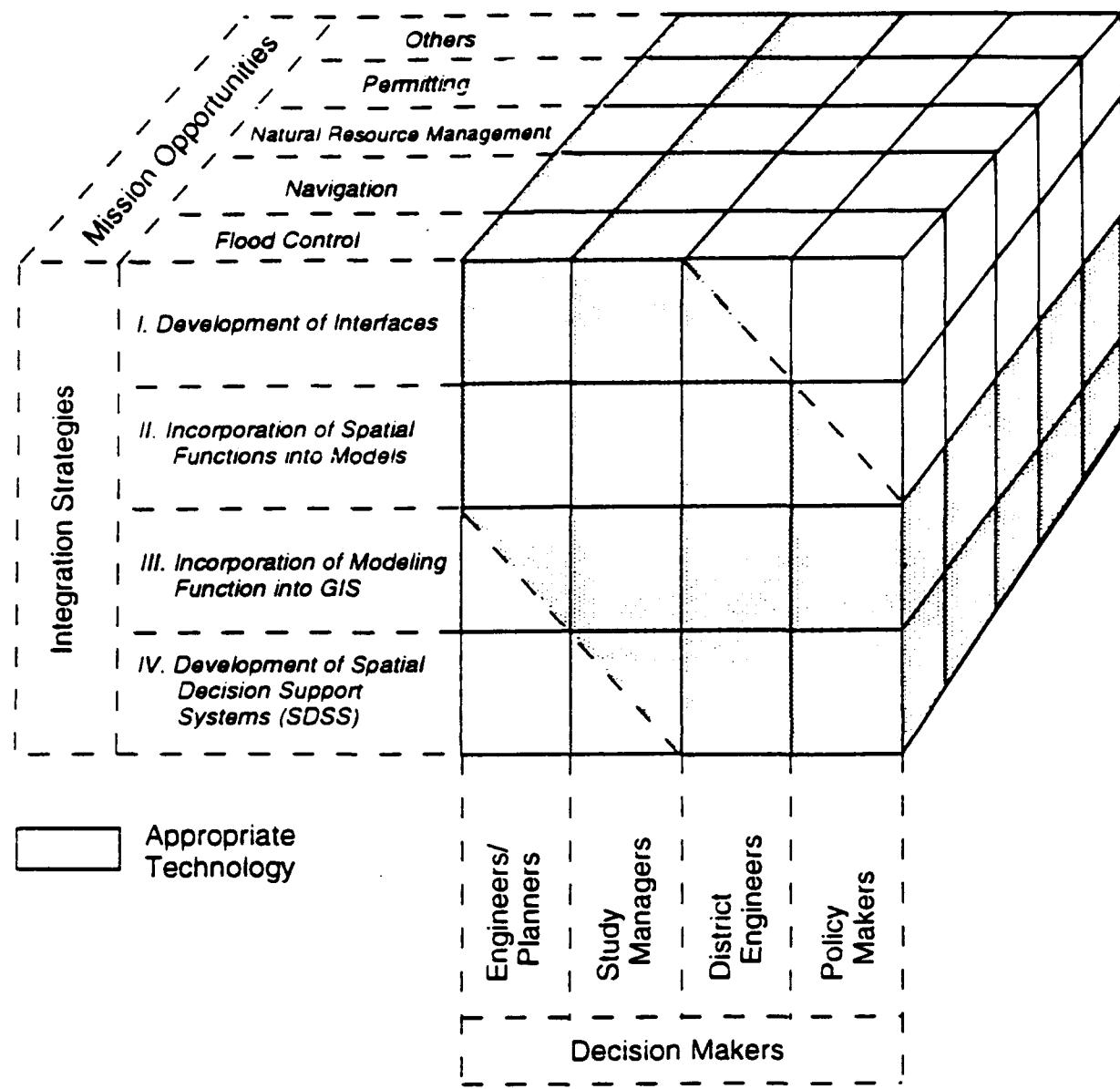


Figure 5. Opportunities Matrix

- An interactive requirements analysis where users are queried concerning their needs and software developers synthesize those needs in the context of a system design for user feedback;
- Development of prototype systems to illustrate and prove concepts; and
- Significant testing and evaluation programs to ensure user needs are met and system utility is as designed.

In many cases, SDSS is an ideal strategy for understanding and addressing Corps planning activities. It is an interface between decision makers and analysts that enables a search for optimal and near-optimal solutions using data bases, models, sensitivity and statistical analyses, multi-criteria decision techniques, and spatially referenced graphics. General activities that will enhance pursuit of SDSS and other integration strategies include:

1. Improving communication within the Corps so that needs and innovations are more widely known;
2. Encouraging the centralized definition of standards and protocols for the interfacing of models, GIS, and data bases, but not a centralized development of SDSS tools;
3. Identifying the most promising candidates for integration from the vast pool of existing models based on relevant characteristics such as the representation of spatial, temporal, and statistical phenomena;
4. Encouraging training in DSS and SDSS technologies and philosophy;
5. Sensitizing Corps software developers to evolving planning needs, especially in less structured decision-making environments ideal for DSS and SDSS;

6. Facilitating discussion of integration priorities in terms of both decision needs (wetlands, flood control, etc.) and technologies (user interfaces, object-oriented programming, data protocols, etc.); and
7. Identifying and evaluating SDSS applications outside the Corps to determine how the issues outlined in this report were addressed, what new issues arose, and how successful the tools are for decision making.

These conclusions and suggestions, based on studying the Corps planning process, will assist the Corps in exploiting new approaches to developing decision-making tools. In turn, the Corps will be able to improve its decision making process.

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## APPENDIX A: PLANNING STUDY REVIEWS

The Corps planning studies which were reviewed have been classified into four categories: Flood Control, Navigation, Shoreline Protection, and Other. Although some reports contain elements of each category, the reports were classified based on their main objective.

### FLOOD CONTROL

Ten flood control reports were reviewed. They are:

1. American River Watershed Investigation.
2. Draft Upper Steele Bayou Project.
3. Arkansas River Basin Feasibility Study.
4. Shoal Creek, Austin, Texas, Interim Report and EA.
5. Rio Grande and Tributaries Interim Feasibility Report.
6. Osage River Basin Summary Feasibility Report.
7. Eastern North Carolina Above Cape Lookout Final Survey Report.
8. Cameron County, Texas, Feasibility Report.
9. Los Angeles County Drainage Area Review Final Feasibility Study.
10. Upper Zocate Creek - Preliminary Draft of Detailed Project Report and EA.

The flood control analysis objective determines the most appropriate measures to reduce flood damages to agriculture and structures while limiting the environmental impacts (wildlife, vegetation, water quality). In each of the proposed plans, hydrologic and hydraulic modeling was performed to estimate flood flows and elevations. These estimates allow determination of economic and environmental effects.

The models applied in the studies provide guidance as to which plan can successfully meet the NED criteria. The models used provide a fast and efficient means to analyze and re-analyze alternate project plans. The studies use several models in analyzing hydraulics and hydrology. However, models of choice are HEC-1 for hydrology and HEC-2 for hydraulics. When HEC-1 and/or HEC-2 were inadequate to model a given situation, other models with additional capabilities were applied. For example, the 2-D hydraulic model FLOW2D was applied in the Upper Zocate Creek study. The models provided flood elevations from which alternatives were evaluated. The studies also applied a wide variety of economic models to determine total damages to agriculture and structures. These models determine damages based on the flood elevations computed in the hydrologic and hydraulic analyses.

Other analytical methods used in the flood control studies included GIS and data base systems. The studies primarily used GIS to organize input and output data and to display results. The GIS facilitated the creation of input data for the hydraulic, hydrologic, and economic models and provided graphical and tabular display capabilities for the model outputs. To a limited extent, some studies used GIS to aid in analysis, loosely linking them with models. Another GIS use combined satellite imagery for mapping and analysis of wetlands.

**Objectives of Study:**

"Provide long term solutions to flood control problems in the Sacramento vicinity..."

- Combine and present flood control information developed by previous studies of the area.
- Determine flood control alternatives based on the information.
- Perform benefit to cost analyses of the alternatives.
- Address environmental issues in selection of preferred alternatives through an EIS.
- Review economic, environmental, public health, and safety issues associated with preferred alternatives.
- Solicit and incorporate public comment.
- Select a recommended alternative.

**Study Approach:**

(Same as above)

**Success in Meeting Objectives:**

The study was a success in meeting its objectives. The technically best alternative was not the socially and environmentally best alternative, but a second alternative was selected to respond to public input. The recommended alternative met the NED criteria, with a benefit to cost ratio equalling 2.7.

**Model Used:**

- Flood frequency used WRC 17-B to determine peak flows expected.
- Hydrological models predicted runoff quantities.
- Unnamed "Hydraulic" model was used to perform backwater calculations.

**GIS Used:**

- Schematics of waterways were computer developed using a CAD or GIS.

**Value Added by Models/GIS:**

Little at this stage of analysis. Most work had already been achieved earlier.

**Missing Information:**

Earlier reports and technical appendices would enable better determination of the precise models and information systems used in study.

**Objectives of Study:**

Reformulation of the remaining unconstructed Main Canal and Black Bayou segments of the Upper Steele Bayou Project in the Yazoo Basin, Mississippi.

**Study Approach:**

- Analyze alternative plans which emphasize:
  - urban flood protection;
  - reducing agricultural intensification; and
  - limiting adverse environmental impacts.
- Existing habitat for waterfowl, fisheries, wetlands, and terrestrial wildlife were based on land use parameters stored in a GIS. The GIS was used to derive stage-area curves, by landuse, based on HEC-1 flood routing. A matrix of effects was established for the alternatives.

**Success in Meeting Objectives:**

An economically feasible plan (benefit to cost ratio of 1.4) was recommended which provides flood protection for urban and agricultural properties, and improved habitat for fish and wildlife.

**Models Used:**

- FORFLO - bottom-land hardwoods succession model (simulates growth of trees).
- Habitat Model - based on multiple regression equations.
- HEC-1/HEC-2 - used in the hydrologic and hydraulic analysis.
- CACFDAS - Computerized Agricultural Crop Flood Damage Assessment System.
- FWS energy model for waterfowl.
- EIFS - Economic Impact Forecast System. This was used in the socio-economic profile and includes not only a database but a system of economic, demographic, and forecasting models.

**GIS Used:**

- A GIS (AGIS by Delta Data Systems) was used to determine cover type, reach boundaries, and to facilitate the evaluation of economic data. It also included satellite imagery.
- Satellite imagery was also used for mapping and analysis of wetlands, specifically a digital map database and acreage statistics for hydric soils, non-hydric soils, and water bodies.

**Value Added by Models/GIS:**

Many models and a GIS were used in this study. These analytical tools, although applied separately, aided in the determination of the NED plan.

**Objectives of Study:**

- Evaluate the usability of Arkansas River as a water supply source.
- To determine the feasibility of new flood control measures.

**Study Approach:**

- Plan formulation.
- Benefit/cost evaluation of alternative plans.
- Environmental considerations.

**Success in Meeting Objectives:**

No action was recommended because none of the proposed projects was deemed economically feasible. The benefit to cost ratios of the alternatives were less than 1.0.

**Models Used:**

Models and analysis tools used in evaluating the alternative plans:

- EAD - Expected Annual Damage computer program package.
- SUPER - Reservoir Regulation Simulation Model.

EAD and SUPER were used in conjunction to determine flood losses to residential, commercial, and farm structures.

- Methodology for estimating fuel and delay costs.
- In conjunction with the SUPER, a methodology for estimating agricultural losses.
- Structural Inventory Damages (SID) computer program.
- Groundwater infiltration model.
- Reservoir rating methodology.
- HEC flood control analysis models.
- EPA's STORET database.

**Value Added by Models:**

Models and computer programs were used as tools to determine the economic feasibility of proposed plans.

**Missing Information:**

Methodology for estimating fuel and delay costs. It is unclear whether it is a computer program or a set of equations.

**Potential to Enhance Study:**

A GIS could have been used in the economic and hydrologic/hydraulic analysis rather than field surveys and aerial photos to facilitate the analysis of alternatives.

**Objectives of Study:**

- Reduce flood damages, provide better health and safety measures, reduce emergency services, and reduce the loss of jobs and/or wages caused by flooding from Shoal Creek within the City of Austin.
- Reduce potential for loss of life due to high velocity flows, isolations caused by floodwaters, and overtopping of bridges and roads along Shoal Creek.
- Preserve and protect existing environmental and aesthetically pleasing areas and maintain, as much as possible, the existing vegetation and animal habitat along Shoal Creek.
- Preserve and/or protect historically significant areas along Shoal Creek in conjunction with flood control measures.

**Study Approach:**

- Evaluate flooding estimates.
- Use hydraulic model to determine water surface elevations of floods.
- Compare to 1981 flood event. (Calibrate model).
- Determine flood control alternatives.
- Select best alternative based on NED guidelines.
- Work with local officials to pick recommended alternative.

**Success in Meeting Objectives:**

Based on the analysis, Federal participation in a flood damage reduction project was justified, and a NED plan was recommended. The City of Austin reviewed the NED plan and decided to implement only a portion of the plan.

**Model Used:**

- HEC-2 (water surface computations).
- Hand calculations for tunnels.
- Proposed Water Quality Models; HEC-5Q, QUAL-W2, and RECOVERY.

**Value Added by Models:**

The different plans were evaluated based on the flood elevations computed by the models.

**Objectives of Study:**

- Identify areas in unstudied Colorado portions of the Rio Grande watershed that pose flood control problems.
- Determine nature, frequency, and extent of floods in these areas.
- Develop alternatives to protect areas from effects of 100-year floods.
- Address environmental issues through an environmental assessment (EA).
- Select a recommended alternative.
- Determine preliminary design and costs of project.

**Success in Meeting Objectives:**

The study achieved its objectives. Some aesthetic issues were left unresolved, but the study was comprehensive given the scope of proposed work.

**Model Used:**

- Computerized flood frequency (WRC 17B).
- HEC-2 used to calculate 100-year flood elevation.
- Computerized economic and scheduling software.

**Value Added by Models:**

The models aided in the determination of the frequency and extent of floods in problem areas. Alternate plans were evaluated using flood elevations calculated by the models.

**Objectives of Study:**

- Determine solutions to flooding and water supply problems. Emphasis was placed on two alternatives based on previous reconnaissance report: (1) creating, combining small lakes for flood control, and (2) use of groundwater instead of surface water sources for water supply.

**Study Approach:**

- Two problem areas were chosen for the study: the Miami Creek Basin and the South Grand river basin. These areas were chosen because they were agriculture intensive with concentrated potential flood damage areas and had a high water supply demand.
- **Flood Control and Water Supply**  
Three plans were chosen as potential solutions to the two problems in each emphasis area:
  - A) Reservoirs were checked for handling of 100-year frequency flood, 100-year sediment yield, and increased where required.
  - B) Change location of reservoirs.
  - C) Develop fewer, larger lakes.
- **Water Supply.**
  - A-E contractor performed water problem survey.
  - Test well constructed to determine suitability of groundwater.
  - Inventory of alternative sources of surface water.
  - Drought contingency planning.
- **Flood Damage Evaluation.** Total agricultural, transportation and structural costs were determined for 10, 25, 50, and 100 year storms.
- **Benefit Cost Analysis.**

**Success in Meeting Objectives:**

Due to a very low benefit to cost ratio (.02), none of the proposed projects could be justified. Flooding and water supply problems were identified, plans were evaluated, but no plan was enacted because funds could not be justified.

**Model Used:**

Not mentioned specifically. On page 6, hydrologic basin models discussed.

**Value Added by Models:**

Unknown

**Missing Information:**

Specific models used to determine flood flows and elevations.

**Objectives of Study:**

Identify water resources problems, specifically related to flooding, and determine if the solutions to address the flooding are economically feasible.

**Study Approach:**

Determine ways of reducing the flooding caused by wind-driven tides by considering alternative plans which consisted primarily of dikes and floodwalls.

**Success in Meeting Objectives:**

Improvements considered were either economically infeasible or lacked the local non-Federal sponsorship. There was no local sponsorship because the plans were either too expensive or aesthetically unpleasing.

**Model Used:**

None. Flood elevations were determined from FEMA. There were no details on how flood damages were calculated.

**Value Added by Models:**

None.

**Missing Information:**

Not a very detailed report compared to others. It is basically a summary of results with no details on methodologies, especially economic estimates.

**Objectives of Study:**

To determine the feasibility of Federal participation in flood control measures to reduce flood damages in Cameron County, Texas, specifically,

- Reduce flood problems in study area.
- Identify existing flood control channels.
- Evaluate feasibility of constructing improvements to flood control channels.
- Assess related environmental and navigation issues.

**Study Approach:**

- Locate data on existing channels.
- Devise flood control improvement structures.
- Simulate the rainfall/runoff process to determine flow rates for each stream.
- For given flow frequencies, calculate channel water surface elevations with and without the proposed improvements.
- Check to see if improvements are economically justified.

**Success in Meeting Objectives:**

The study concluded that no improvements were justified using NED criteria. The study applied benefit to cost analysis to each stream segment investigated. The highest ratio equaled 0.9. All information was turned over to the non-Federal sponsor for subsequent local sponsor analyses.

**Model Used:**

- HEC-1 for rainfall/runoff analyses and determination of SPF information.
- HEC-2 for water surface profile computations.
- Various unnamed models for supplemental design flows.
- Spreadsheets to perform simpler economic and hydraulic calculations.

**GIS Used:**

GIS used in conjunction with CAD system to serve as database of channel x-section, input & output information.

**Value Added by Models/GIS:**

The study would be difficult without models to perform calculations and databases to organize data. Tidal nature of some portions of the channels revealed limitations in HEC-2. The use of a 2-D model would raise confidence in the results. The computer generated illustrations and output graphics made technical assessment much easier.

**Potential to Enhance Study:**

The use of a more sophisticated model to simulate time variable water surface elevations. HEC-2 is not the most appropriate model.

**Objectives of Study:**

- Determine if existing Los Angeles County Drainage Area (LACDA) mainstream system adequately protects Los Angeles from floods.
- Determine frequency, capacity, and extent of floods occurring in the mainstem system.
- Prepare alternatives to mitigate and protect LACDA from 100-year frequency events.
- Address environmental issues in selecting an alternative through an EIS.
- Review water conservation, recreation, environmental enhancement, and transportation needs with regard to the selected alternatives.
- Solicit and incorporate public comment.
- Choose a recommended alternative.

**Study Approach:**

- Define the extent of the mainstem system.
- Re-evaluate rainfall/runoff estimates.
- Re-evaluate existing system capacity.
- Define nature and extent of floods.
- Formulate flood control alternatives.
- NED assessments.

**Success in Meeting Objectives:**

The NED plan was selected but the validity of the scientific and engineering efforts was questioned. Critics felt the study did not produce enough alternatives or adequately address all of the issues. This report criticizes the computer models used in determining water levels but uses the results in selecting an alternative. This uncertainty invalidates their credibility.

**Model Used:**

- Statistical models for determining design rain/flow (increased period of record increased predictive qualities).
- Traffic simulation model (evaluate bridge modifications).
- Seismic model to ascertain dam stability (increased load resulting from additional water volume).
- Hydrologic models predicting runoff quantities.
- Hydraulic models predicting flood elevation (questionable accuracy because of unsteady flow conditions - page 121).
- Reservoir operating models.
- Hydraulic model to be built at WES.
- GIS or CAD derived schematics showing mainstem systems.

**Value Added by Models/GIS:**

The models provided impetus for re-evaluation of the sites. The results drove the selection of the recommended alternative, although accuracy of the results was questioned.

**Missing Information:**

Missing Part II of the report.

**Objectives of Study:**

Examine the water and land resources issues to determine if a flood control plan should be implemented.

**Study Approach:**

There were two phases in the study:

- A reconnaissance phase which identified a detention pond plan as a potential flood control measure.
- A feasibility phase - Alternative solutions for flood control are developed and evaluated. The recommended plan was chosen based on best benefit cost ratio consistent with NED.

**Success in Meeting Objectives:**

The objectives were met. Alternative plan with best B/C ratio was chosen for implementation.

**Model Used:**

- SWFHYD - Southwestern Division, Fort Worth District, Hydrology Package. It was used to compute synthetic rainfall runoff volumes and unit/flood hydrographs, routing flood hydrographs downstream, and to tabulate frequency peak discharges.
- FLOW2D - 2D flow model to determine water surface elevations. This is the primary hydraulic model.
- HEC-2 - the FLOW2D model was used when a study reach was encountered which was difficult to model with HEC-2.

**GIS Used:**

- A GIS model was developed to assist in the calculation of economic damages caused by different flood events.
- GRASS was used for evaluation of structure damage.

**Value Added by Models/GIS:**

Models and GIS were used to determine the extent of flooding and monetary damage amounts so a best plan could be formulated to remediate the damages. Based on the Model/GIS results, the most effective (best B/C ratio) plan was implemented.

## NAVIGATION

There were five navigation reports reviewed. They are:

1. Navigation Study for Canaveral Harbor, Florida - Final Feasibility Report and EIS.
2. Morehead City Harbor Improvement, NC - Feasibility Report and EA.
3. Navigation Study for Miami Harbor - Final Feasibility Report.
4. Lower Cumberland and Tennessee Rivers - Final Feasibility Study.
5. Delaware River Comprehensive Navigation Study Interim Feasibility Report.

The primary objective of these studies was determining appropriate channel enhancements to allow larger ships and improve navigation efficiency. The analysis in these studies consisted of determining the economic benefits of increased navigation based on market projections for different channel geometries. Models used in the reports were economic in nature. The models estimated tonnage capacities and commodity amounts for in-place projects. One study used a decision support system (DSS) to determine suitable dredged material disposal areas. Some studies also employed models which estimated cost due to shoaling and dredging. The accompanying environmental analyses limited modeling to water quality issues, specifically the use of salinity models to determine project impacts on salinity distribution.

For reports which were a success in meeting their objectives, modeling played an important role in determining benefits and costs of alternate plans. Some of the navigation studies used economic modeling while others used market projections and spreadsheet analysis to determine navigation benefits. The studies which made use of models and GIS appeared more likely to have proposed projects implemented, in part because a wider range of alternatives could be easily evaluated. Economic analysis in the no-model studies could benefit from a computerized methodology. A link to graphics would enhance the quality of the presentations.

**Objectives of Study:**

Enhancement of the harbor to increase navigation efficiency.

**Study Approach:**

- Maximize the application of NED.
- Check EIS.
- Increase tonnage of fuel oil, gasoline, cement, scrap.
- Data used in study - X-sections, soil types, economic information.

**Success in Meeting Objectives:**

Good. The benefit to cost ratio was 1.3. A 25% cost share with enthusiastic local sponsor (Port Authority).

**Model Used:**

I/O, Market Projections.

**Value Added by Models:**

None. The calculation of navigation benefits seems to be a methodology that could be computerized (perhaps already on spreadsheets).

**Potential to Enhance Study:**

The study could be enhanced with a data base, interfaced with the econometrics, and linked to graphics. Graphics would improve quality of presentation.

**Objectives of Study:**

Evaluate need for and feasibility of improvements to Morehead City harbor, specifically to deepen and widen the harbor to allow safe navigation for oceangoing vessels which export phosphate rock and coal.

**Study Approach:**

Plan formulation consisted of evaluating alternative channel depths and identifying that depth which would produce maximum net benefits (NED).

**Success in Meeting Objectives:**

Yes. Plan with a benefit-cost ratio of 1.8 was approved.

**Model Used:**

- Spreadsheet analysis, Market Projections.
- In Water Quality section of EIS, a salinity distribution analysis was done using a one-dimensional dispersion analysis model, which consists of a few equations.

**Value Added by Models:**

*The methodology for computing navigation benefits and cost could be computerized.*

**Potential to Enhance Study:**

Use of models (i.e., Tow Cost Model) with data base to determine economically best plan.

**Objectives of Study:**

Determine Federal role in local interests' request for sediment removal in the Miami Harbor to improve navigation efficiency and reduce pollution.

**Study Approach:**

- Inventory and assess water resource problems and their relationship to economic and environmental needs.
- Develop alternative solutions and their associated costs, benefits, and environmental impacts.
- Select the best plan.

**Success in Meeting Objectives:**

Water quality (dredging) and navigation work could not be justified economically, but maintenance dredging of the Miami River was recommended.

**Models Used:**

None. Analysis mostly focused on sampling and testing for water quality.

**Objectives of Study:**

- Reduce transportation costs.
- Provide safe and dependable commercial navigation.
- Conserve fish and wildlife and other natural resources in the Tennessee and Cumberland Rivers.
- Reduce lockage delays to navigation traffic.
- Maintain navigation traffic to maximum extent during project construction.
- Minimize adverse effects to recreational boating due to construction of project.

**Study Approach:**

Identify and evaluate range of alternatives that will achieve aforementioned objectives.

- Establish without - Project condition - used as a baseline against which alternatives are based. Basically, it is maintenance costs of existing locks.
- Establish with - Project alternatives.
  - Preliminary alternatives - broad measures with several variations/combinations. Generally, whether or not to continue considering an alternative is based on economic analysis (benefit to cost ratio).
  - Intermediate Alternatives - further screening of plans - based on benefit to cost analysis.
  - Final Plans - intermediate alternatives refined, evaluated, and compared. Final plans developed include without - project condition and three alternatives. Three alternatives are the construction of three different size locks. (Plans A, B, and C). Plan A was determined best.

**Success in Meeting Objectives:**

Under the NED plan chosen, the economic, environmental, and social objectives were met.

**Model Used:**

Tow Cost Model (TCM).

**GIS Used:**

Unspecified GIS used the in EIS.

**Value Added by Models/GIS:**

Modeling aided in the economic evaluation of alternatives.

**Missing Information:**

Volume I is a non-technical summary. Other volumes (II, IV), which were not provided to GKY&A, contain technical details. TCM was used to analyze traffic interactions and estimate the National Economic Development (NED). Details of model are found in Volume IV, appendix D.

**Objectives of Study:**

To address and evaluate current problems such as:

- adequacy of facilities.
- delays in intermodal transfers.
- channel dimensions.
- storage locations and capacities.
- other physical factors affecting waterborne commerce on the Delaware River.

**Study Approach:**

- plan formulation.
- alternative plans.
- recommend plan based on NED.

**Success in Meeting Objectives:**

Recommended plan based on NED with benefit to cost ratio of 1.33.

**Model Used:**

- Dredged Material Disposal Management Model (D2M2).
- World trade models (DRI), were used to model international trade. Non-econometric estimates based on propensity models were also used.
- In the EIS, a salinity model, the Transient Salinity Intrusion Model (TSIM) was applied.

**GIS Used:**

Though not specifically called a GIS, a computerized data management and analysis tool to handle "spatial" or mapped data (called Spatial Analysis Methodology, SAM) was used. It consisted of a database, analysis programs, and graphical display features.

**Value Added by Models/GIS:**

Economic models used in analyzing cost effectiveness of alternative plans. SAM used in selecting best areas for the disposal of dredged material.

## SHORELINE PROTECTION

Three shoreline protection studies were reviewed. They are:

1. Final Feasibility Report and EIS on Hurricane Protection and Beach Erosion Control.
2. Gulf Intercoastal Waterway Feasibility Report and Final EIS.
3. Chesapeake Bay Shoreline Erosion Study Feasibility Report.

These reports focused on the need to provide shoreline protection for threatened coastal communities. The general steps involved in shoreline analysis include determination of the magnitude of erosion, examining and evaluating a range of protection solutions, and recommending specific projects for implementation. Modeling in these reports dealt mainly with shoreline change, economics, and hydraulics to a limited extent. There were no GIS applied in these studies.

Models used in the erosion studies focused on shoreline change simulation and methodologies to compute economic benefits of in-place projects. The studies use shoreline change models to estimate future shoreline positions and to assist in beach nourishment design. Applying site-specific data and economic models allowed estimates of hurricane and storm damage. Models screened alternate protection plans to determine the most feasible NED plan.

**Objectives of Study:**

- Investigate shore protection needs at Topsail Island.
- Develop a plan which will reduce hurricane and storm damages and beach erosion.
- Enhance the beach strand available for recreational use.

**Study Approach:**

- Identify problem areas, public interest, and need for erosion protection.
- Estimate potential economic benefits if plan implemented.
- Identify environmental impacts.
- Plan formulation, alternatives, plan selection.

**Success in Meeting Objectives:**

The NED plan was not chosen because it included a terminal groin, which is not regulation. A non-groin plan was selected and an exception to the NED requirement was approved.

**Model Used:**

Economic benefits analysis done using real estate appraisal data. Hurricane and storm damages were computed using Wilmington District computer programs. Recreation benefits computed using data from coastal management plan.

**Value Added by Models:**

Economic benefits and damage amounts were calculated and used in analyzing alternative plans.

**Missing Information:**

Information on model (computer programs) which estimate annual hurricane and storm damages.

**Potential to Enhance Study:**

Appendix C and D present equations used in the analysis which may or may not be computerized.

**Objectives of Study:**

- Determine magnitude of erosion.
- Examine range of solutions.
- Evaluate effectiveness.
- Recommend specific projects.
- Determine Federal, State, and local responsibilities.

**Study Approach:**

- Inventory/Screening to identify high erosion areas.
- Generalized Bay-wide estimates of benefits and costs to generate benefit to cost ratios.

**Success in Meeting Objectives:**

Lack of Federal authority in most areas of shoreline limited identification of many site-specific projects or bay-wide strategy. Minimal direct activity seems to have resulted from study, i.e., specific projects.

**Model Used:**

No models actually used (In reference section, Hanson and Kraus are authors of GENESIS: Generalized Model for Simulating Shoreline Change, CERC TR89-19). Some mapping and aerial photography was used to identify/evaluate erosion sites.

**Value Added by Models:**

None added.

**Objectives of Study:**

Determine feasibility of maintaining the navigability of the Gulf Intracoastal Waterway (GIWW) which is being threatened by erosion.

**Study Approach:**

- Identify problems.
- Plan formulation.
- Plan evaluation.
- Selection of NED plan.

**Success in Meeting Objectives:**

The NED plan was chosen ( $b/c = 2.3$ ). It consists of a 42,000 foot long barrier located between the Gulf and the GIWW.

**Models Used:**

- COAST - used in the shoreline change analysis.
- SBEACH - model used for beach nourishment design.
- BERM - BEach profile Re-Molder.
- ACES - Automated Coastal Engineering System - used to determine average wave height.
- Economic (spreadsheet) models to compare alternative plans.

**Value Added by Models:**

Models used in the assessment and screening of alternative plans, of which NED plan was chosen.

**Missing Information:**

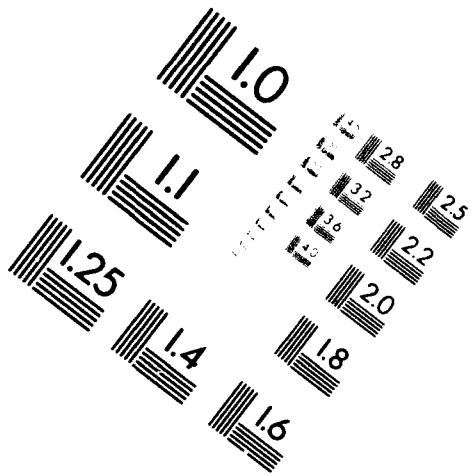
None.



**AIIM**

**Association for Information and Image Management**

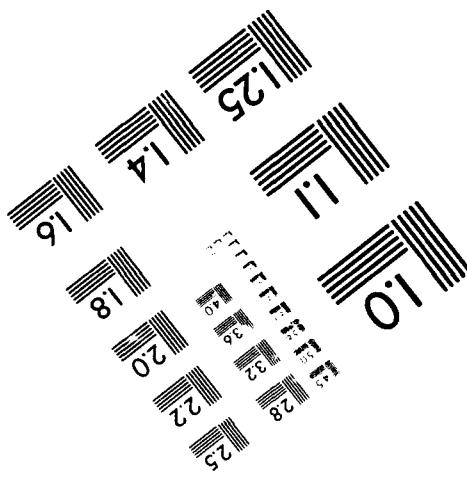
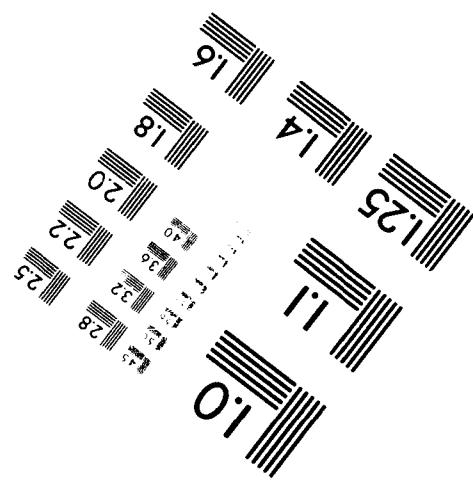
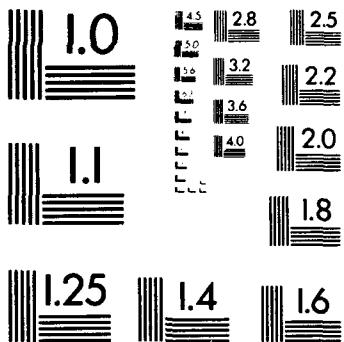
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**Centimeter**



**Inches**



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## OTHER PLANNING STUDIES

The Denison Dam-Lake Texoma study had several water resource objectives. For this reason, it is included under a separate heading. Of interest is the power network allocation model used in the study. The Prototype Methodology Study, which investigated the feasibility of model and GIS integration, is also included in this category.

**Objectives of Study:**

Determine if modification of project scope will satisfy current and future water resources needs.  
The needs include:

- Maintain or increase flood control protection.
- Reduce lake elevation fluctuations.
- Increase hydroelectric power production.
- Reduce sediment inflow.
- Protect environment.

**Study Approach:**

- Develop alternatives.
- Evaluation how each alternative satisfies objective.
- Elicit public input.
- Select proposed alternative.

**Success in Meeting Objectives:**

No action recommended. The benefit to cost ratios were low (0.06) for many of the alternatives. The need for flood control storage is based on recent flooding events.

**Model Used:**

POWERSYM (page 72, 20 of EA) modeled economics of hydroelectric power generation. Differing inflow/elevations were viewed.

**Value Added by Models/GIS:**

The POWERSYM model balanced losses of capital during shut-down versus added capacity. No benefits were realized.

**Missing Information:**

More information on POWERSYM program and results.

**Objectives of Study:**

"To investigate different methods by which the GIS could be integrated into the water and land resources planning for feasibility-level investigations..." More specifically to "automate computer linkages between GIS, HEC-1, HEC-2, and an economic flood damage model.

**Study Approach:**

Select a prototype (subset) area to actually apply the methodology.

**Success in Meeting Objectives:**

A series of tools, called *f-tools*, was developed to automate linkages between models and GIS. The study group was satisfied with their efficacy and is proceeding to expand the study.

**Model Used:**

- HEC-1/HEC-2
- Economic Damage Model

**GIS Used:**

- GRASS
- ARC/INFO

**Value Added by Models/GIS:**

The f-tool linkages, once accepted for the overall Trinity River Study, will greatly reduce the amount of tedious data formatting and manipulation normally involved in a study such as that of the Upper Trinity River Basin.



## APPENDIX B: SITE VISITS AND INTERVIEWS

### SITE VISITS

During site visits, information and commentary were gathered on analytical methods developed or applied by the Corps. Six sites were visited during the study: the Hydrologic Engineering Center (HEC), the Waterways Experiment Station (WES), the Construction Engineering Research Laboratory (CERL), the Cold Regions Research Engineering Laboratory (CRREL), the Fort Worth District, the Vicksburg District, and the Lower Mississippi Valley Division. At several locations, advanced GIS/modeling activities are taking place in a research context. Part of the discussions addressed coordination of lab activities and dissemination of technologies developed and used in the laboratory to the District.

The following discussion identifies interesting and important concepts under development or applied at the sites. Some of the Corps staff visited during the site visits include:

Andy Bruzewicz	- CRREL
Mike Burnham	- HEC
Cary Butler	- WES (Geotechnical Laboratory)
Steve Cobb	- Lower Mississippi River Valley Division
Darryl Davis	- HEC
Paul Eagles	- Vicksburg District (Planning Division)
Michael Gee	- HEC
Bill Goran	- CERL
Mark Graves	- WES (Environmental Laboratory)
Bill Johnson	- WES (Hydraulics Laboratory)
Bill Johnson	- HEC
Dave Johnson	- Vicksburg District (Engineering Division)
Rose Kress	- WES (Environmental Laboratory)
Perry LePotin	- CRREL
Ike McKim	- CRREL
Nolan Raphelt	- WES (Hydraulics Laboratory)
Richard Schneider	- CERL
Scott Walker	- Ft. Worth District
Jerry Wiley	- HEC
Al Williamson	- WES (Information Technology Laboratory)

### Hydrologic Engineering Center

The Hydrologic Engineering Center, located in Davis, California, develops and supports software products for the Corps and the international engineering community. The orientation in software development is toward deterministic or stochastic simulation of physical phenomena, rather than optimizing a series of alternatives. HEC has experience in developing tools for water resources applications with spatial components. An example is the Spatial Analysis Methodology which HEC developed to assist in floodplain management. Several factors have limited the efficiency and flexibility of these earlier tools. Specifically, the Federal Insurance Agency perceived the capability to intrude on their area of responsibility. Data storage technology at that time was also not nearly as sophisticated as it is today.

HEC has several alternatives to address these limitations. The NexGen system, under development, uses object-oriented processes to ensure flexibility and diversity. HEC initially specifies the platforms, interfaces, data management, and output components, allows creation of analysis modules based on a stable system foundation. The system represents a risk for HEC developers in that NexGen attempts to forecast future water resources analytical methods. A goal is to have a future product ready when users have the technical capability to apply it.

One HEC suggestion is for the Corps to try to prepare for future engineering and planning questions, such as infrastructure and environmental aspects of water resources. The Corp may also need national rather than site-specific planning activities, such as the National Drought Study, which places different demands on spatial analysis capabilities. These questions may require HEC to change its planning process to adapt to new analytical needs.

### Construction Engineering Research Laboratory

The Construction Engineering Research Laboratory (CERL), located in Champaign, Illinois, supports Corps environmental and infrastructure missions. The orientation of the infrastructure mission is toward local design and planning on military installations. The analytical tools are typically CAD systems. The environmental mission requires analyses of larger sites or projects, where analytical methods, such as GIS, allow data synthesis and visualization.

The CERL Environmental Lab developed and maintains the GIS product, GRASS, which is intended to combine input, analytical, output, and mapping functions. The developers note that many users regard the product as a data engine. Enhancements to GRASS include increased graphical and data management abilities and support of increasingly diverse hardware and software platforms. These types of abilities will enable the user community to complete more sophisticated analyses. The CERL developers have made the most active effort to transfer these tools to the public. The feedback and comments they then receive make their analytic tool more robust and applicable to the needs of the user community. However, graphic manipulation using GRASS software is time consuming, which may limit its usefulness in real-time applications, where more rapid response is required.

### Waterways Experiment Station

The Waterways Experiment Station (WES), located in Vicksburg, Mississippi, conducts hydraulic, environmental, and geotechnical research to support Corps civil and military missions. Analytical methods include both physical and software developed systems. As a research arm of the Corps, WES has experience in several diverse water resource areas, and is adept at developing new and adapting existing technologies to address water resources issues.

WES Hydraulics Laboratory staff described an Intergraph-based integration of GIS and SCS peak flow modeling to design riser pipes to prevent erosion. A major part of the effort has been to develop the data and integrate the modeling capability into the GIS. It is premature to assess the success of the effort.

Environmental Lab staff described extensive applications of GRASS, ARC/INFO, and ERDAS. They expressed a need for standardization, but acknowledged the differing benefits of each product. They also noted differing needs for precision in engineering and planning disciplines. At times, engineers are more reluctant to apply GIS because of perceived flaws in precision.

Personnel at the Information Technology Laboratory summarized efforts in reaching standards conventions for Corps CAD activities. They viewed the need for standardization in the GIS area to be of primary importance.

Military activities are also taking place at WES. Geotechnical Laboratory staff provided an impressive demonstration of the TERRACAMS battlefield decision support system. Although significant training is required to use TERRACAMS effectively, it appears to reflect many of the features of decision support: real time use (under stressful conditions) and adaptability to different sites and conditions.

### Cold Regions Research and Engineering Laboratory

The Remote Sensory/GIS Center (RSGISC) at the Cold Regions Research and Engineering Laboratory (CRREL), located in New Hampshire, concentrates efforts on the applicability and transfer of the analytical methods. Several activities are currently underway at the RSGISC. A major initiative is the incorporation of spatial data and Object Oriented Programming (OOP) into hydrological models. Some coordination of this activity has occurred with HEC. One of the tools employed is STELLA, which provides an object-

oriented approach to solving differential equations in a Macintosh environment. Although STELLA is limited to the Macintosh, they emphasized their objective of keeping software and hardware architecture open.

Another area of work is in visualization, primarily for emergency operations. An example on dambreak simulation planned in the Omaha District in December of 1992 was described. CRREL hopes that visualization will facilitate certain tasks that are currently being accomplished by the "seat of the pants."

The third major area of work addressed is remote sensing and image processing. OOP is also being applied to improve remote sensing capabilities and SARAH, a sister analysis tool to STELLA, is useful for image processing.

In addition to describing and demonstrating their work, the following general comments were shared.

- GIS is useful for boolean-type modeling.
- GIS appears most appropriate for planning and operations, but less so for engineering.
- Integration of models and GIS requires cross-discipline work without professional chauvinism.
- A problem with "pretty" images is that it is difficult to know how "real" they are.

#### Fort Worth District

The Fort Worth District developed the f-tools linkages discussed earlier in the report. District staff applies analytical methods in a creative and sophisticated manner. When applied to projects, the tools demonstrate practical usefulness. This experience gives the District analysts unique perspectives on the pros and cons inherent in using new technologies.

One viewpoint expressed by some District staff is that applying these analytic tools requires a focus of resources and time. The processes used in integration must be well understood to prevent a perception of a "black box and black lines." The District analysts believe that feedback plays an important role in applying the tools.

#### Vicksburg District

Vicksburg District personnel are enthusiastic about the value of GIS and modeling in enhancing their capabilities. Activities include interpreting remote sensing data for incorporation into GIS data bases. Some staff would like to see GIS further incorporated into day-to-day activities based on their experience in using GIS in planning studies.

## Lower Mississippi Valley Division

Lower Mississippi Valley Division personnel are supervising the Lower Mississippi Environmental Program that applies a GIS for land inventory purposes. Originally, the program used a custom GIS called the Computerized Environmental Resources Data System. Now, the program is transferring the operation to GRASS because it needs expanded coverages and detail.

## ADDITIONAL INTERVIEWS

In addition to the site visits, interviews were conducted of other Corps personnel with expertise in the analytical fields of interest. Persons outside the Corps were also interviewed to broaden the experience base.

The practitioners interviewed during this process included:

Dr. Steve Chase	- FHWA (Turner-Fairbank)
Mr. Michael Danella	- Corps (Fort Worth District)
Mr. Steve Dressing	- EPA (Headquarters)
Mr. Roger Gauthier	- Corps (Detroit District)
Mr. Gene Maak	- Corps (Charleston District)
Mr. William McFarland	- USGS (Oregon)
Mr. Doug Nebert	- USGS (WRD, Reston, Virginia)
Mr. Bob Pease	- EPA (Headquarters)
Mr. Tim Peterson	- Corps (Omaha District)
Mr. Bob Pierce	- USGS (Atlanta, Georgia)
Mr. Michael Scuderi	- Corps (Seattle District)

Water resources practitioners vary in their approaches and viewpoints regarding application of analytic tools. The diversity of opinion can even be found within the same organization, and usually reflects the specific role of the practitioner within an organization.



## APPENDIX C: ANALYTICAL TOOLS

The following discussion provides details on the analytical tools applied in the planning studies. The tools are organized by type in the following general categories: Hydrology/Hydraulics, Economics, Water Quality, Shoreline Analysis, and Geographical Information Systems/Databases.

### HYDROLOGY/HYDRAULICS

- HEC-1 is a model developed by the Corps that simulates the precipitation and runoff characteristics of a watershed. Widely used, the model allows a synthetic determination of a design flood, simulating both hydrologic and hydraulic processes. HEC-1 offers many different methodologies to calculate a series of hydrographs. Synthetic hydrograph methods create results that represent the dynamic nature of rainfall and the hydraulic effects of overland and channel flow. The input uses land use characteristics of the watershed to determine the quantity of runoff from a design storm event. Data quantity and quality limit model accuracy. Input data may consist of several hundred lines. The output has a similar level of detail and sophistication. Design storms provide the model with the probabilistic frequency associated with the runoff flows. The model also performs sophisticated hydraulic analyses such as channel routing, dam break, and snow melt situations. The model incorporates recent hydrological and hydraulic concepts and procedures, which lead to a high level of acceptance of the model by the American engineering community. Continued Corps support insures that HEC-1 will continue to be a robust model.
- WRC-17B refers to a class of models that apply Water Resources Council (WRC) bulletin 17-B methodologies to determine the flood frequency of a gaged stream. The models are stochastic in nature. The model goals are to calculate a flow associated with some probabilistic event. The primary inputs are peak 1-day flows for several water years. The larger the period of record, the more accurately they describe a flow distribution for the stream. Another input can be the desired frequency (return period). Output results consist of the flow associated with the desired frequency, as well as other typical design and project flows. A probability plot may depict the distribution of the design floods and the flows used as inputs. The models use the Log Pearson Type III methodologies in the statistical analysis. Calculation by-products include the mean, standard deviation, and skew coefficient. The WRC-17B methodology allows use of regional skew coefficients as replacements for the computed values. Some models allow this skew coefficient substitution. Since the input data consists of measured stream flows, the results are

more accurate than those produced in a deterministic manner (rainfall-runoff models). However, proper use limits application to those streams having an adequate, measured record of flow. The soundest application of the models is at sites where a stable level of development exists. The models cannot forecast changes in flows resulting from land use changes of the watershed. This makes them less flexible than other hydrology models.

- The Stormwater Management Model (SWMM) is a USEPA developed model that simulates the rainfall/runoff relationship for both quantity and quality of flow. The model has complex hydrologic and hydraulic elements that produce and transport flows in an urban setting. Model operations include the ability to simulate either design storm or continuous rainfall events. The flow conveyance includes both open channel flow and storm drain systems. SWMM can simulate the effects of surface and subsurface flow in a watershed. The model inputs include rainfall hyetographs, land use, topography, and physical conditions. These inputs generate hydrographic flow that the model routes through the watershed. The quality portion of the model can simulate the transport of conservative chemical and biological constituents. The model is popular and has a stable user base. SWMM operates on both mainframe and microcomputer platforms.
- The NUDALLAS model, developed by the Fort Worth District, simulates the precipitation/runoff characteristics of a watershed. Model capabilities include computation of synthetic rainfall, runoff volumes, unit hydrographs, and flood hydrographs. The model can route hydrographs produced from several subareas through a system of channels. The inputs are land use information (such as soil type and impervious area) for each subarea. Another model input is design rainfall intensities for a variety of storm durations. The model uses Snyder's method to calculate flow and develop hydrographs. The model uses modified Puls to route the hydrographs. The Fort Worth District uses NUDALLAS because it has relatively simple input requirements. The model provides the District with flexibility that other hydrology programs lack. Both the District and the local engineering community apply the model to a variety of hydrological projects.
- The Southwestern Division, Fort Worth District, HYdrology Package (SWFHYD), applied in the Upper Zocate Creek study, computes the synthetic rainfall, runoff volumes, unit/flood hydrographs, routes flood hydrographs, and tabulates assorted frequency peak discharges. Inputs include 1- to 500-year rainfall data and subarea data for existing and future (with project) conditions. Model output is the expected peak discharges for different flood frequencies for each subarea.

HEC-2 calculates the water surface elevation along a stream or channel. Knowledge of the water surface elevation allows an assessment of a channel's ability to contain and transport flood waters. The model calculates water surface elevations which can be used to represent the floodplain associated with a flow. The model calculates the water surface elevation by applying conservation of energy and continuity principles. The model assumes uniform, gradually varying, one-dimensional flow. The model can simulate sophisticated hydraulic concepts, such as bridge constrictions. Model application is usually after first using a hydrology model to determine a design flow. Primary inputs consist of channel elements (cross-section coordinates, slopes, locations, and roughness characteristics) and flows and initial elevations. The primary model outputs include the water surface elevations, velocities, and conveyance at each cross section. The model can produce plots of the water surface elevation along the channel profile. HEC-2 is a widely used model in flood control.

FLOW2D is a hydraulic model used to determine water surface elevations for flood events. The model is a derivative of the Southwestern Division two-dimensional flow program, FLOWSIM10, and was applied in the Zocate Creek study. The model's two-dimensional nature can simulate more complicated hydraulic sites than conventional one-dimensional models (such as HEC-2). Model input parameters include Manning's n, inflow hydrographs, and a study area description. The study area description uses grid cells to represent streams and tributaries two-dimensionally. The study used the FLOW2D model because floodplain geometry could not be easily modeled using a one-dimensional model. Reasons for using the 2D model include: partially perched channel with associated overland flow, combination of super-critical flow in the channel and sub-critical flow in the overbanks, split flows, and multiple tributary openings.

The Groundwater Infiltration Model (GIM) is under development by the U.S. Geological Survey (USGS). It is used to determine the average daily recharge rate from a river to the groundwater. A draft version of the model was applied to the Arkansas River. It allowed predictions of the interaction between the river and the water table. The model results provided a first run estimate, with results subject to change based on the more detailed, fully developed model.

The Southwestern Division Reservoir Regulation computer model (SUPER) is a hydrologic/economic model which computes daily discharges and flood damages. The Arkansas River report applied and updated the model for use in the study. SUPER facilitated economic analyses by simulating different operating plans. The model simulates hydrology and hydraulics by using a historical hydrologic period of record. The model, which includes an economic data base, allows for an estimate of agricultural and structural flood damages for different flood frequencies.

## ECONOMICS

- The Expected Annual Damage (EAD) package, developed by HEC, computes expected annual equivalent flood damages. Inputs include depth-damage coefficients for several types of structures including residential, commercial, and farm structures. The program uses these inputs to generate output stage-damage curves. The program is useful for comparing damages under alternative plans.
- The Structural Inventory Damage (SID) model, developed by HEC, determines flood damages to structures based on flood elevations. Model inputs, obtained through a survey, include navigation miles of the structures, type of construction, value of the structure, type of contents (if the structure was commercial), and distance from the first floor to a reference flood elevation. Model results are elevation versus damage tables applied to index stations described in the input.
- The Computerized Agricultural Crop Flood Damage Assessment System (CACFDAS) is a crop damage model developed at Mississippi State University along with USDA and Delta Branch Experiment Station personnel and the Mississippi Cooperative Extension Service. The Upper Steele Bayou Project applied the model to compute flood damages for various crops for different flood events. Data input to the model includes information on yields, production practices, and resource use rates. Research scientists and extension specialists at experiment stations produce this information. Farm producers from the survey area supply crop budget data reflecting typical management practices. Crop budget data include production costs, harvest equipment costs, expected net returns to lands, management and farm overhead, and operating revenues (the gross value of the harvested crop). The main input to the program is hydrologic daily stage data for the project area. Other data include the date, associated elevation of flooding, and the number of cleared acres flooded for each daily stage. The program bases flood damage calculations on time of the flood event and how the flood affects agricultural operations that occur in the crop production process.
- The Economic Impact Forecast System (EIFS), developed by the Environmental Technology Information System, is a data base along with economic, demographic, and forecasting models. The system develops socioeconomic data profiles and economic impact assessments. The Upper Steele Bayou project used the system to perform economic evaluations of proposed water resource improvements. The data base contains economic and demographic data which include the following: population, labor force, employment, earnings, income, farm characteristics, and past, present, and future economic development.
- The Southwest Division developed a shoaling model to estimate delay costs due to shoaling (blocked navigation). The model uses time-cost data along with dredging requirements associated with different flood events. Other inputs include the

seasonal cost per day for blocked navigation and a relationship representing percent blockage associated with the dredge pass order number.

- The Dredging Volume model simulates the amount of shoal formation and the removal of shoaling over time based on an index station period of record hydrography. The dredging requirement basis is a correlation which relates peak discharge of a flood event to the required dredging volume. Dredge volume records for a particular time frame were chosen to calibrate the model. Model calibration occurs by adjusting the peak discharge versus required dredging correlation curve until the average annual dredging estimated by the model for the time frame approximated the actual average annual amount for the period. The model estimates dredging costs by determining a cost per cubic yard of dredged material based on dredging cost data of previous years.
- The Dredged Material Disposal Management (D2M2) model, used in the Delaware River Navigation study, analyzed the disposal costs of dredged materials for alternative plans. The model analyzes different disposal plans by considering factors such as shoaling rates, initial construction quantities, disposal area capacities, and annual operation and maintenance costs. The model determined the most efficient means for disposal of dredged material in previously screened sites.
- The Delaware River Navigation study used DRI World Trade models to simulate international trade. The purpose of the study was to determine the adequacy of the channel for physical (channel dimensions) factors affecting waterborne commerce. The study used the models to estimate future trends in trade and how the future amounts (tonnage) of cargo would affect the need to enhance the Delaware River. The application of the models developed commodity projections for crude oil, coal, and iron ore. Using commodity specific factors such as imports and exports among major developed market economy countries, along with DRI macroeconomic forecasts, the models generated world trade trends for the specific commodities. For each country, the models use import and export flows over a 10-year period as input data. The models then develop commodity forecasts to determine tonnage amounts of each commodity coming into or leaving the Port of Philadelphia.
- The Tow Cost Model (TCM) was used in the Lower Cumberland and Tennessee Rivers feasibility study. This model was chosen for the analysis due to the complexity of the navigation system and the large quantities of data involved. The model estimated tonnage capacities for each lock in the river system to determine economic benefits for each plan. (Study report Appendix D, currently unavailable, provides details of model inputs and operation.)

## GEOGRAPHICAL INFORMATION SYSTEMS/DATA

- The Geographical Resources Analysis Support System (GRASS) is a public domain geographic information system developed by the Corps. The system performs on a UNIX-based computer platform and provides software tools for performing analyses. In a flood control context, the system provided a means to gather, synthesize, display, and output geographic and land use information. This ability aids production of input data for hydrologic, hydraulic, and economic models. GRASS also offers the ability to manipulate and display model results. The ability to function as a pre- and post-processor for models speeds the data accumulation process and reduces errors. System inputs included soil data, land use data, and topographic contour information. The data sources included remote sensing (Landsat, ERDAS), existing maps, topographic files (DEM), and synthesized information. Linking GRASS to an economics data base allows prediction of flood damages resulting from a design storm. The GRASS applications also include wetlands delineations.
- The Computerized Environmental Resources Data System (CERDS) is a geographic information system for the Lower Mississippi River. The system allows investigation of environmental issues associated with flood control projects on the river. The hardware platform for CERDS is a MS-DOS computer with EGA graphics. Input and mapped data available to the system include elevation and topographic, land cover, aquatic habitats, cultural features, soils, and swales. The data sources included remote sensing and historical records. The resolution of the information is not high. CERDS uses include assessments of vegetation types, determination of volumes and acreage, and other spatial information of the sort produced by a geographic information system. The CERDS source code is in PASCAL. This would make portability between operating systems difficult.
- The ARC/INFO system, developed by the Environmental Systems Research Institute, is a proprietary geographic information system and relational data base manager. Several studies used the system as a tool for data synthesis and incorporation into flood control models. Of the planning reviews, only the Trinity River prototype study used the package. In that study, the Corps used ARC/INFO as an engine to produce information that an earlier version of GRASS could not. The study transferred the resulting data to GRASS. The literature and practitioners have used ARC/INFO in other prototype flood control/hydraulic studies. One study linked ARC/INFO with the SWMM model to review a combined sewer system (*Chase, 1991*). In both ARC/INFO and GRASS, these linkages are computer programs customized to the particular application, platform, and software.
- STORET refers to the USEPA environmental data base and in-house software systems. STORET is one of the largest civilian data bases in the world. The data base contains files on water quality, geographical, physical, hydrological, chemical

and toxic monitoring, and biological species. Recent software additions have enabled STORET data to be displayed and manipulated in a spatial manner. EPA efforts seek to enhance this geographic information system capability.

The Spatial Analysis Methodology (SAM), is a set of analytical tools integrated to process spatial data. Used primarily for flood damage reduction and expanded floodplain information studies in the late 1970s and early 1980s, it can be applied to a variety of problems. For example, it was used in the Delaware River navigation study, to determine suitable dredged material disposal areas. SAM is a computerized data management and analysis package which handles "spatial" or mapped data. The basic elements of SAM are a data base of geographical characteristics and computer programs to perform analysis functions. The methodology involves storing appropriate mapped data and defining criteria (parameters) for disposal areas. The system searches for characteristics which satisfy the defined criteria. The system also can produce output in a graphical or tabular format for further analysis. Several parameters determined disposal site selection. These parameters include archaeologic and historic sites, sensitive fish and wildlife areas, wetlands, navigation features and groundwater protection zones. The package assigns each parameter a weighting factor based on relative importance or "attractiveness" for dredged material disposal. The SAM package, using the defined parameters and criteria along with geographic information, produces scaled maps which graphically represent attractiveness zones, or potential disposal areas. Besides SAM, the study also used other data to screen for disposal sites. These data included aerial photographs, interviews and local officials, review of previous reports, and public notices.

## WATER QUALITY

- The Transient Salinity Intrusion Model (TSIM), used in the final Environmental Impact Statement within the Delaware River Navigation study, determined how channel widening alters the salinity regime. Specifically, the model simulated whether the change in channel shape would cause an increase in saltwater penetration, and thus affect the marine environment. The model simulations used hydrology data from a drought of record and two different channel geometries, the present channel, and the deepened channel. The model output was maximum intrusion of the 250 mg/l isochlor, and the 30-day average of the maximum chloride concentration. The model results predicted that deepening the channel would not violate existing salinity standards.
- The Morehead City Harbor Improvement study applied a one-dimensional salinity model to estimate the salinity increase resulting from channel deepening and other project improvements. The model consists of three equations used to calculate total flow and salinity concentrations of effluent at the discharge and upstream points. Inputs include tributary and effluent flow rates and salinity concentrations at the discharge and upstream points. The model used available data from 1974 and 1978

in performing the analysis to determine the potential for salinity increase. The model results revealed that deepening the harbor would not significantly impact the salinity distribution.

- HEC-5Q was developed by the Hydrologic Engineering Center and is designed to simulate flow and water quality in reservoir systems. The water quality capabilities include analysis of temperature, non-conservative and conservative constituents. Common parameters have included pH, dissolved oxygen, total dissolved solids, BOD, fecal coliform, nitrate, and phosphate.

## SHORELINE ANALYSIS

- The Automated Coastal Engineering System (ACES), applied in the Gulf Intercoastal Waterway (GIWW) report, determined average wave height. The GIWW report used 20 years of historical statistics to determine the mean significant wave height at the toe of the proposed structural revetment. The ACES transformed the annual mean significant deep water wave to a shallow water wave.
- The Topsail Beach report included equations which calculated percent wave energy and annual wave energy flux. The report correlated the wave energy flux to estimated shoreline changes to determine sediment transport rates.
- The COAST model analyzed the shoreline change analysis in the GIWW study. The study used the model, digitized high water lines, and aerial photographs to calculate areas and distances. The analysis divided the shoreline area into 2,000-foot transects for measurement purposes. Graphical displays of analysis results showed the high water line and the maximum landward movement for each transect over the 46-year study period. A table of shoreline statistics also documented maximum movement and erosion rates at each transect. Using average erosion rates for different periods within the 46-year time frame for each transect allowed estimation of future shoreline positions and determination of when and where a breach would occur.
- The beach fill model (SBEACH) simulates beach nourishment design. Numerical modeling of beach profile equilibrium slope and fill template shape determines a design profile. The BEach profile Re-Molder program (BERM) calculates the volume of fill material. Inputs to SBEACH include; mean grain size of the native beach, mean grain size of the borrow area, and the sorting value of the native beach and the borrow. Examination of historic trends in wading depth profiles aids in the determination of beach nourishment requirements. The model and historic data were used to calculate the rate of beach erosion under natural conditions, along with the amount of fill required to protect the beach for a certain period. Reviewing the project and measuring erosion on an yearly basis allows assessment of renourishment needs.

The Topsail Beach report applied computer programs to calculate hurricane and storm damages. The Wilmington District initially developed these programs to model riverine flooding. The district altered the program to measure coastal storm damages. Inputs to the program consist of specific structural data. These include structural values, ground and flood elevations of structures, location, distance from the midpoint of the structure to the projected mean high water line, and estimated contents value. The program calculates a damage-frequency relationship and average annual damage for each structure. The study applied the program in the with and without project condition, for each structure, to determine total damages.